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ANALYSIS OF STALL FLUTTER OF A HELICOPTER ROTOR BLADE

by Peter Crimi

Prepared by
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for Langley Research Center

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16. Abstract
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ANALYSIS OF STALL FLUTTER

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By Peter Crimi
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SUMMARY

A study of rotor blade aeroelastic stability was carried out, using an analytic model of a two-dimensional airfoil undergoing dynamic stall and an elastomechanical representation including flapping, flapwise bending and torsional degrees of freedom. Results for a hovering rotor demonstrated that the models used are capable of reproducing both classical and stall flutter. The minimum rotor speed for the occurrence of stall flutter in hover was found to be determined from coupling between torsion and flapping. Instabilities analogous to both classical and stall flutter were found to occur in forward flight. However, the large stall-related torsional oscillations which commonly limit aircraft forward speed appear to be the response to rapid changes in aerodynamic moment which accompany stall and unstall, rather than the result of an aeroelastic instability. The severity of stall-related instabilities and response was found to depend to some extent on linear stability. Increasing linear stability lessens the susceptibility to stall flutter and reduces the magnitude of the torsional response to stall and unstall.

INTRODUCTION

Aeroelastic stability of a helicopter rotor blade is a multifaceted problem because of the extreme variations of the aerodynamic environment within the flight envelope of the aircraft. In hovering flight, a blade can undergo classical binary flutter (Ref. 1) or stall flutter (Ref. 2). In forward flight, the linear instability experienced by systems with periodically varying parameters can occur (Ref. 3). While these types of instability are not normally encountered with blades of current design, due to the relatively low disc loading and weak coupling of translational and rotational degrees of freedom, they are certainly not precluded from new designs, particularly those intended to extend present performance capabilities. Of immediate concern, however, in both design and operation, is the occurrence of large-amplitude torsional oscillations and excessive control-linkage loads associated with blade stall on the retreating side of the rotor disc at high forward speed or gross weight, effectively limiting aircraft performance. This problem has prompted a number of recent studies of dynamic stall and the effects of stall on blade dynamics (Refs. 4-8).

While stall has been identified as a causal element of the problem, the nonlinearity of the stall process, coupled with the unsteady aerodynamic environment, has precluded an analysis to the depth required to gain a thorough understanding of the mechanisms involved. In particular, it has not been clear whether the blade undergoes a true aeroelastic instability, a simple forced response, or some hybrid phenomenon which takes on the character of one or the other extreme, depending on flight conditions and blade vibrational characteristics.

Stall flutter for axial flight is amenable to analysis by empirical methods similar to those developed for analyzing stall flutter in cascades (Ref. 9). The flutter mechanism for that case has been identified as deriving from the extraction of energy from the free stream by the periodic variation of the aerodynamic moment. Analogous methods applied to the forward-flight problem (Refs. 10 and 11) have been inconclusive, however, the primary difficulty possibly being in applying empirical methods without a clear definition of the underlying mechanism of the problem.

A method was recently developed for analyzing dynamic stall of an airfoil undergoing arbitrary pitching and plunging motions which provides an ideal tool for analyzing the stall problem in forward flight. The method, which is described in detail in Ref. 7, employs models for each of the basic flow elements contributing to the unsteady stall of a two-dimensional airfoil. Calculations of the loading during transient and sinusoidal pitching motions are in good qualitative agreement with measured loads. Dynamic overshoot, or lift in excess of the maximum static value, as well as unstable moment variation, are in clear evidence in the computed results.

This study was directed to analyzing the aeroelastic stability of a helicopter rotor, particularly as it relates to stall, using the method of Ref. 7 to compute aerodynamic loading. The representation of the elastomechanical system includes flapping and flapwise bending degrees of freedom as well as torsion. A listing of the computer program used to perform the calculations is given in Appendix A.

SYMBOLS

b	blade semichord, m
$\overline{C}_L$	mean lift coefficient, ratio of time average of l to $\rho \Omega^2 R^2 b$
C_l	lift coefficient, $C_l = c_l / (\rho U^2 b)$
$C_{m\ c/4}$	moment coefficient referred to quarterchord, $C_{m\ c/4} = m_{c/4} / (2 \rho U^2 b^2)$
c	blade chord, m
f_θ	mode shape of first uncoupled torsional mode, unit tip deflection
f_ϕ	mode shape of first uncoupled flapwise bending mode, unit tip deflection
h_β	tip deflection due to flapping, semichords
h_ϕ	tip deflection due to bending, semichords
h_i	translational coordinates of 2-D system $(i = 1, 2)$, semichords
I_o	moment of inertia of 2-D system about pitch axis, kg - m
I_θ'	blade moment of inertia about elastic axis per unit span, kg - m
k_i	translational spring stiffnesses of 2-D system $(i = 1, 2)$, N/m^2
k_θ	torsional spring stiffness of 2-D system, N/rad
l	lift per unit span at aerodynamic reference radius, N/m
l_{s_i}	offsets of springs from pitch axis of 2-D system $(i = 1, 2)$, m
M_b	total blade mass, kg
m	blade mass per unit span, kg/m
$m_{\ c/4}$	aerodynamic moment per unit span at aerodynamic reference radius, N

m_i	masses of 2-D system, kg/m
R	rotor radius, m
r_o	inner radius of blade lifting surface, m
r_R	aerodynamic reference radius, m
U	instantaneous free-stream speed at aerodynamic reference section, m/sec
U_o	reference speed, $U_o = \Omega \; r_R$, m/sec
x_m	distance aft of elastic axis of blade section mass center, m
$\overline{x}$	distance aft of pitch axis of mass center of m_1, m
Z_β	generalized coordinate of 2-D system, equivalent to h_β , semichords
$Z_\emptyset$	generalized coordinate of 2-D system, equivalent to $h_\emptyset$, semichords
α	angle of attack, deg
δ	flapping hinge offset, m
θ_o	collective pitch angle, deg or rad
θ_1	blade tip torsional deflection, rad
$\tilde{\theta}$	angle of zero restraint of 2-D system torsion spring, rad
μ	advance ratio, ratio of forward speed to Ω R
ρ	free-stream density, kg/m^3
τ	dimensionless time, $\tau = U_o \, t/b$
ψ	blade azimuth angle measured from downwind direction, deg or rad
Ω	rotor rotational speed, rad/sec
Ω^*	dimensionless rotor speed, $\Omega^* = \Omega R/(\omega_{\theta_o} b)$
ω_f	flutter frequency, rad/sec

ω_{θ_o} frequency of first uncoupled, nonrotating torsion mode, rad/sec

ω_{ϕ_o} frequency of first uncoupled, nonrotating flapwise bending mode, rad/sec

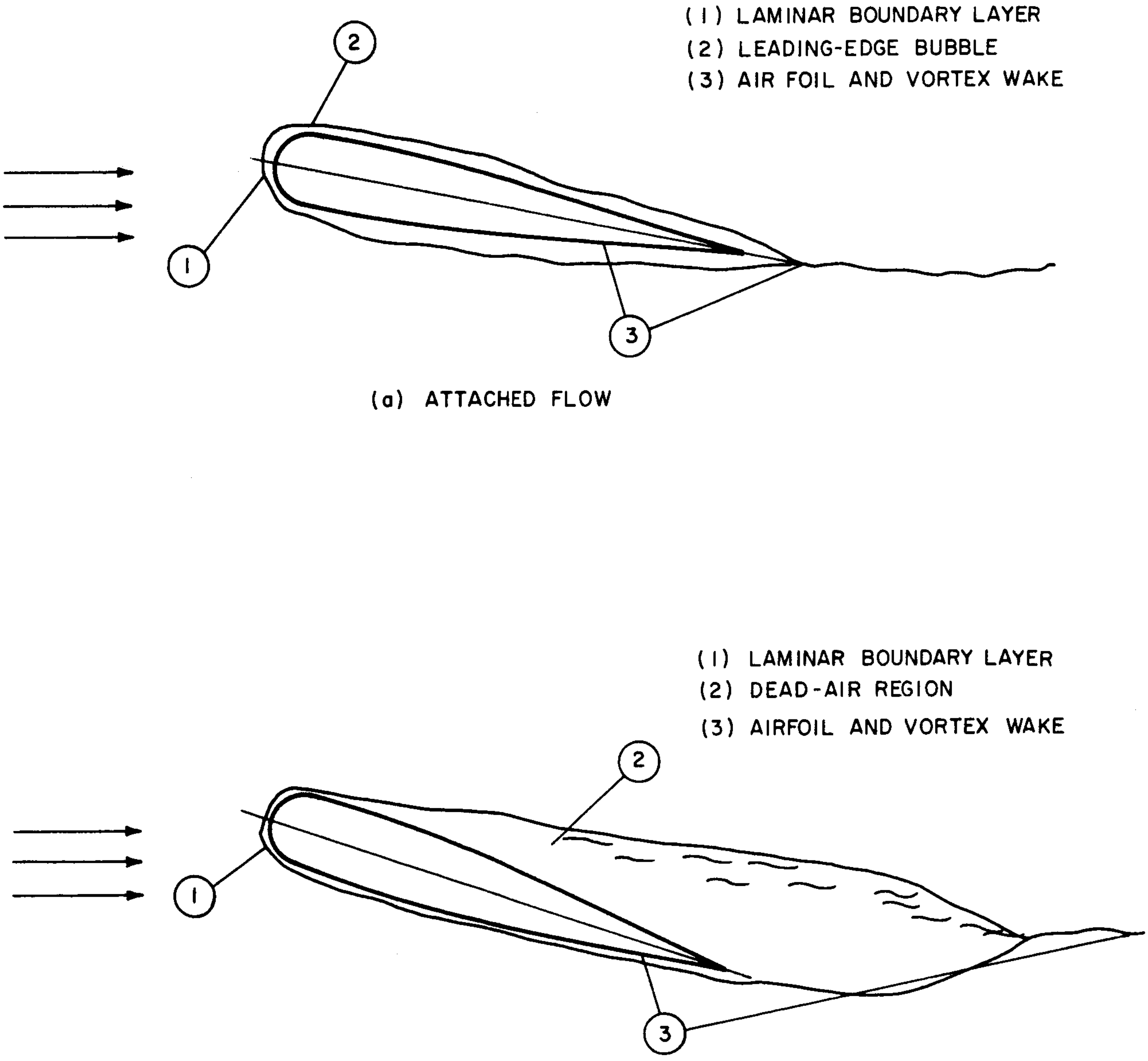
PROBLEM FORMULATION

Aerodynamic Loading

In the flutter analysis, only leading-edge stall was considered, so the following relates specifically only to that type, even though the basic method can treat trailing-edge stall as well. When the airfoil is not stalled, the flow elements represented are (see Figure 1a): (1) the laminar boundary layer from the stagnation point to separation near the leading-edge, (2) the small leading-edge separation bubble; and, (3) a potential flow, including a vortex wake generated by the variation with time of the circulation about the airfoil. When the airfoil is stalled, as indicated in Figure 1b, the flow elements are: (1) the laminar boundary layer, (2) a dead-air region extending from the separation point to the pressure recovery point; and, (3) a potential flow external to the airfoil and dead-air region, again including a vortex wake. The analytic representations of these elements are described briefly below. Details are given in Ref. 7.

Potential Flow.—Given the airfoil section characteristics and motions, together with the distribution of pressure in the dead-air region if the airfoil is stalled, the flow and pressure over the airfoil must be determined to compute the integrated load and analyze the boundary layer. The problem was formulated by imposing linearized boundary conditions of flow tangency and pressure, using a perturbation velocity potential derived from source and vortex distributions. The resulting coupled set of singular integral equations is solved by casting the singularity distributions in series form and solving for the unknown coefficients by imposing boundary conditions at prescribed points.

Boundary Layer.—Because the relative importance of the individual elements of the boundary layer flow as they affect dynamic stall could not be established in advance, the representation in Ref. 7 was made as general as possible. The method of finite differences for unsteady flows with variable step size in both streamwise and normal directions, was employed, with the error in each finite-difference approximation the order of the square of the step size. It was determined from preliminary calculations performed for this study that, at least for leading-edge stall, results are virtually unaffected by assuming quasi-steady flow in the boundary layer. That assumption was therefore employed for all flutter computations, to take advantage


(1) LAMINAR BOUNDARY LAYER
(2) LEADING-EDGE BUBBLE
(3) AIR FOIL AND VORTEX WAKE
2
1
3
(1) LAMINAR BOUNDARY LAYER
(2) DEAD-AIR REGION
(3) AIRFOIL AND VORTEX WAKE
2
1
3

(a) ATTACHED FLOW

(b) LEADING-EDGE STALL

Figure 1 FLOW ELEMENTS

of the resulting substantial savings in computer storage requirements and computing time.

Dead-Air Region.—The function of the model of the dead-air region is to define the streamwise distribution of pressure in that region, given the locations of the separation and recovery points and the pressure at the recovery point. The dead-air region is assumed to consist of a laminar constant-pressure free shear layer from separation to transition, a turbulent constant-pressure mixing region, and a turbulent pressure-recovery region. The laminar shear layer is analyzed by the method of Ref. 12, assuming quasi-steady flow. The turbulent mixing and pressure-recovery regions are analyzed using the steady-flow momentum integral and first moment equations. Profile parameters in these regions are assumed to be universal functions of a dimensionless streamwise coordinate, with those functions derived from an exact viscous-inviscid interaction calculation. Matching of approximate solutions for the mixing and pressure-recovery regions at their interface completes the analysis.

Leading-Edge Bubble.—The leading-edge bubble on an unstalled airfoil is analyzed using the same basic relations employed for the dead-air region. Given the boundary-layer parameters at separation, the length of the bubble and the amount of pressure rise possible, for that length, in the pressure recovery region, are computed. That pressure rise is compared with the rise in pressure in the potential flow over the length of the bubble. If the latter is greater than the former, the bubble is assumed to have burst, and the stall process is initiated.

Loading Calculation Procedure.—Calculations proceed by forward integration in time, using the blade motions derived by integrating the equations of motion of the elastomechanical system. If, at a given instant, the airfoil is not stalled, the potential flow is computed, and the boundary layer and leading-edge bubble are analyzed to check for bubble bursting. If the airfoil is stalled, the pressure distribution in the dead-air region is computed, the potential flow evaluated, and the boundary layer is analyzed to locate the separation point. The last two steps are repeated iteratively until assumed and computed separation points agree. Rate of growth of the dead-air region is determined from an estimate of the rate of fluid entrainment derived from the potential-flow solution. Unstall is determined by first postulating its occurrence and analyzing the leading-edge bubble which would then form to ascertain whether that event did in fact occur.

During unstall, the dead-air region is washed off the airfoil at the free-stream speed.

Elastomechanical Representation

The equations of motion for a rotor blade with flapping, flapwise bending and torsional degrees of freedom can be written in the form (Ref. 3)

$$\frac{d^2 h_\beta}{d\,\tau^2} + \frac{R}{b}\,\frac{M_{\beta\,\theta}}{M_{\beta\beta}}\,\frac{d^2\theta_1}{d\,\tau^2} + \bar{\omega}_\beta^{\;2}\,h_\beta - \frac{R}{b}\,\bar{\Omega}^2\,\frac{T_{\beta\,\theta}\,\theta_1}{M_{\beta\beta}} = \frac{Rb}{U_o^{\;2}}\,\frac{F_\beta}{M_{\beta\beta}}$$

$$\frac{d^2 h_\phi}{d\,\tau^2} + \frac{M_{\phi\theta}}{b\,M_{\phi\phi}}\,\frac{d^2\theta_1}{d\,\tau^2} + \bar{\omega}_\phi^{\;2}\,h_\phi - \bar{\Omega}^2\,\frac{T_{\phi\theta}}{M_{\phi\phi}}\,\theta_1 = \frac{b}{U_o^{\;2}}\,\frac{F_\phi}{M_{\phi\phi}}$$

$$\frac{d^2\theta_1}{d\,\tau^2} + \frac{b}{R}\,\frac{M_{\beta\,\theta}}{M_{\theta\theta}}\,\frac{d^2 h_\beta}{d\,\tau^2} + \frac{b\,M_{\phi\theta}}{M_{\theta\theta}}\,\frac{d^2 h_\phi}{d\,\tau^2} + \bar{\omega}_\theta^{\;2}\,\theta_1 - \frac{b}{R}\,\bar{\Omega}^2\,\frac{T_{\beta\,\theta}}{M_{\theta\theta}}\,h_\beta - \bar{\Omega}^2\,\frac{b\,T_{\phi\theta}}{M_{\theta\theta}}\,h_\phi = \frac{b^2\,F_\theta}{U_o^{\;2}\,M_{\theta\theta}}$$

where h_β and h_ϕ are tip displacements due to flapping and bending, respectively, in semichords, θ_1 is torsional displacement at the blade tip and the frequencies* are the following functions of rotational speed:

$$\bar{\omega}_\beta^{\,2} = -\bar{\Omega}^2 \frac{T_{\beta\beta}}{M_{\beta\beta}}, \quad \bar{\omega}_\phi^{\,2} = \bar{\omega}_{\phi_o}^{\,2} - \bar{\Omega}^2 \frac{T_{\phi\phi}}{M_{\phi\phi}},$$

$$\bar{\omega}_\theta^{\,2} = \bar{\omega}_{\theta_o}^{\,2} - \bar{\Omega}^2 \frac{T_{\theta\theta}}{M_{\theta\theta}}$$

The inertial and centrifugal-force coefficients are given by

$$M_{\beta\beta} = \int_\delta^R (r+\delta)^2 \, m dr, \quad M_{\phi\phi} = \int_\delta^R m \, f_\phi^{\,2} \, dr,$$

$$M_{\theta\theta} = \int_\delta^R I_\theta' \, f_\theta^{\,2} \, dr,$$

$$M_{\beta\theta} = -\int_\delta^R m \, x_m (r-\delta) \, f_\theta \, dr,$$

$$M_{\phi\theta} = -\int_\delta^R m \, x_m \, f_\phi \, f_\theta \, dr,$$

$$T_{\beta\beta} = -\int_\delta^R r (r-\delta) \, m \, dr,$$

*Barred quantities are dimensionless frequencies, U_o/b being reference frequency; e.g., $\bar{\Omega} = \Omega \, b/U_o$.

$$T_{\phi\phi} = - \int_{\delta}^{R} f_{\phi}'^{\,2} \left\{ \int_{r}^{R} r_1 \, m \, (r_1) \, d \, r_1 \right\} dr,$$

$$T_{\theta\theta} = - M_{\theta\theta}, \qquad T_{\beta\theta} = - M_{\beta\theta},$$

$$T_{\phi\theta} = \int_{\delta}^{R} (r - \delta) \, f_{\phi}' \, f_{\theta} \, m \, x_m \, dr$$

The complexity of the aerodynamic representation precludes evaluation of the generalized forces F_β , F_ϕ and F_θ by the usual strip approximation. It was felt essential, however, to retain both translational degrees of freedom in the investigation of the forward-flight problem, so a simple two-dimensional model of the dynamics could not be used. Therefore, a two-dimensional airfoil suspended in such a way as to have three degrees of freedom was analyzed. Inertial and stiffness parameters were assigned to make the coupled natural frequencies of the two-dimensional system match those of the rotor blade.

The system analyzed is shown schematically in Figure 2. The matching of the two-dimensional system with the blade dynamics proceeds as follows. Three generalized coordinates are first defined to correspond to those of the blade. Clearly, angular displacement θ_1 should correspond to blade torsional displacement at the blade tip. The counterparts of flapping and bending, Z_β and Z_ϕ, respectively, are defined by

$$Z_\beta = A_1 \, h_1 + Bh_2, \quad Z_\phi = A_2 \, h_1 - Bh_2$$

$$\text{where} \quad A_1 = \frac{\bar{\omega}_\beta^{\,2} - \bar{\omega}_2^{\,2}}{\bar{\omega}_\phi^{\,2} - \bar{\omega}_\beta^{\,2}}, \quad A_2 = \frac{\bar{\omega}_2^{\,2} - \bar{\omega}_\phi^{\,2}}{\bar{\omega}_\phi^{\,2} - \bar{\omega}_\beta^{\,2}},$$

$$B = \frac{(\bar{\omega}_2^{\,2} - \bar{\omega}_\phi^{\,2})(\bar{\omega}_2^{\,2} - \bar{\omega}_\beta^{\,2})}{(\bar{\omega}_\phi^{\,2} - \bar{\omega}_\beta^{\,2}) \, \bar{\omega}_2^{\,2}} \qquad (1)$$

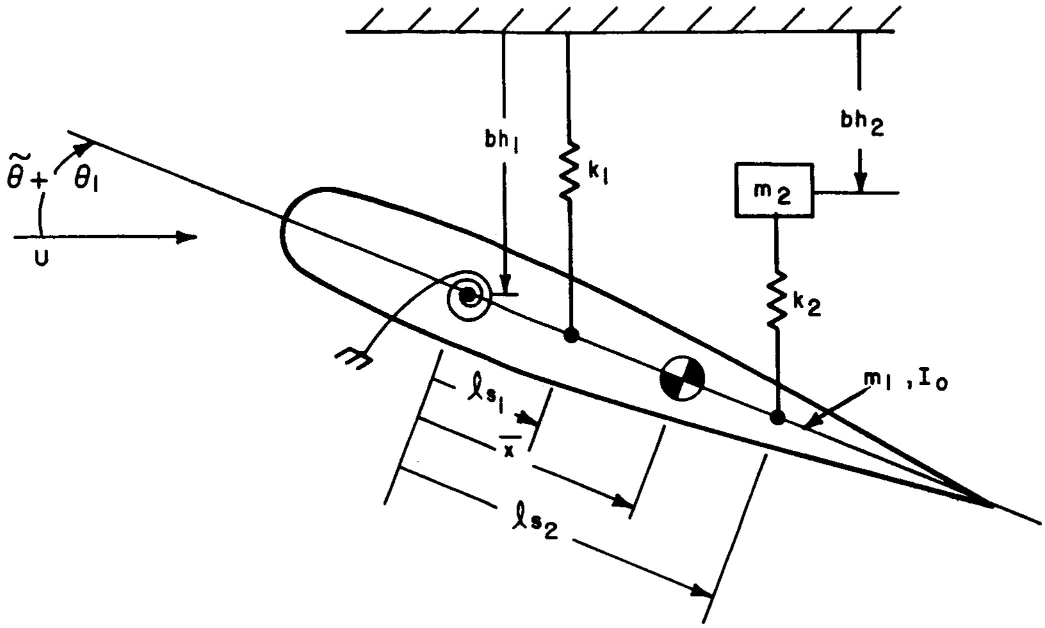


Figure 2 TWO-DIMENSIONAL ELASTOMECHANICAL SYSTEM

and $\bar{\omega}_i^2 = (k_i/m_i)(b/U_o)^2, \quad i = 1, 2.$

With the above definitions, $Z_\beta + Z_\phi = -h_1$, to give the correct translational correspondence. It can further be shown that the uncoupled natural frequencies of the two-dimensional system match those of the blade, provided

$$\left(\frac{k_\theta + k_1 \, l_{s1}^2 + k_2 \, l_{s2}^2}{I_o}\right)\left(\frac{b}{U_o}\right)^2 = \bar{\omega}_\theta^2$$

while $\bar{\omega}_1^2$ and $\bar{\omega}_2^2$ satisfy

$$\bar{\omega}_1^2 \; \bar{\omega}_2^2 = \bar{\omega}_\phi^2 \; \bar{\omega}_\beta^2 ,$$

$$\bar{\omega}_1^2 + (1 + m_2/m_1) \; \bar{\omega}_2^2 = \bar{\omega}_\phi^2 + \bar{\omega}_\beta^2 \qquad (2)$$

By comparing the generalized masses of the two systems, it follows that

$$m_1 \, b^2/I_o = - A_1 \, M_{\beta\beta} \; b^2/(M_{\theta\theta} \, R^2)$$

$$A_2/A_1 = M_{\beta\beta} \; /(M_{\phi\phi} \, R^2) \equiv \lambda_m$$

The last relation, together with Eqs. (1) and (2), fixes m_2/m_1:

$$m_2/m_1 = \frac{(1 + \lambda_m)(\bar{\omega}_\phi^4 + \lambda_m \; \bar{\omega}_\beta^4)}{(\lambda_m \; \bar{\omega}_\beta^2 + \bar{\omega}_\phi^2)^2} - 1$$

Equating the corresponding coefficients of the characteristic equations of the two systems provides three additional relations, which can be solved for the coupling parameters $\bar{x}$, l_{s1}, l_{s2}. That calculation is outlined in Appendix B.

To complete the matching, quasi-steady approximations to the damping terms of the flapping equations are equated with the result that

$$m_1 \; R/(-A_1) \;=\; 4 \, \frac{r_R}{R} \; \frac{M_{\beta\beta}}{R^2 \left[1 - (r_o/R)^4\right]}$$

$$U/U_o \;=\; 1 + \frac{4}{3} \left[\frac{1 - (r_o/R)^2}{1 - (r_o/R)^4} \right] \mu \sin \psi$$

where $\Omega \, r_R = U_o$. The aerodynamic reference radius r_R was selected to be .75R.

The angle of zero restraint in torsion was varied periodically to approximate the effects of cyclic pitch variation in forward flight, according to the formula

$$\tilde{\theta} \;=\; \theta_o \; \left[1 - 2 \; (R/r_R) \;\; \mu \sin \psi\right]$$

This variation gives nominally constant lift.

The equations of motion were solved by integrating analytically, using linear extrapolations to approximate the variation of lift and aerodynamic moment over the interval of integration. This scheme was found to give satisfactory results, provided the time interval of integration is no longer than about one fifth of the period of the coupled mode having the highest natural frequency.

RESULTS OF COMPUTATIONS

Configurations Analyzed

Vibrational and aerodynamic characteristics of the blade analyzed were selected to correspond to those of the model rotor blade described in Ref. 2. That blade is untwisted, of constant chord, with offset flapping hinge. Pertinent dimensionless parameters of the model blade are listed in Table 1.

TABLE 1

BLADE PARAMETERS FOR NOMINAL CONFIGURATION

Parameter	Value
b/R	.0435
δ/R	.0543
r_o/R	.174
$\omega_{\theta_o}/\omega_{\phi_o}$	3.69
$\rho R\ b^2/M_b$	.00431
x_m/b	.216
$m\ R/M_b$	1.055
$I'_\theta\ /M_b\ R$	3.51×10^{-4}

Two elastomechanical configurations in addition to the nominal one were analyzed. One of these had $\omega_{\theta_o}/\omega_{\phi_o} = 2.5$, with all other parameters as listed in Table 1. The third configuration had $x_m/b = .108$, with the remaining parameters as listed in Table 1.

The bending mode shape, which was computed by a finite-element method, was found not to vary appreciably over the range of rotational speeds of interest. The mode shape for $\omega_{\phi_o}/\Omega = 1.26$, which is plotted in Figure 3, was used for all computations. The torsional mode shape for the nonrotating blade, also shown in Figure 3, was used to evaluate torsional inertia parameters.

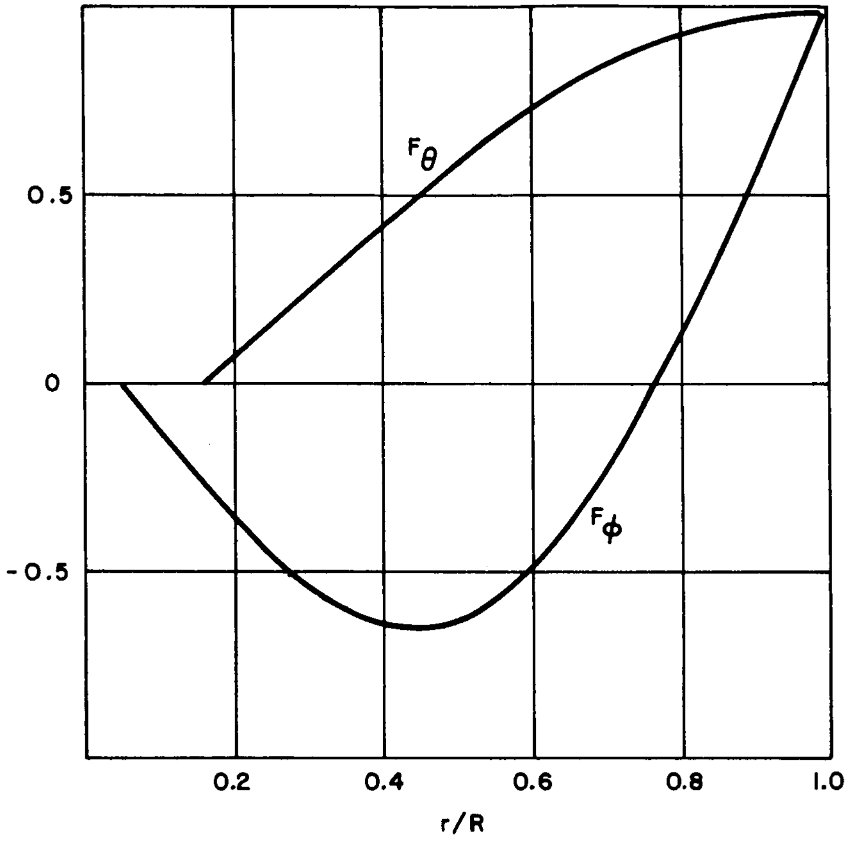


Figure 3 BENDING AND TORSION MODE SHAPES

The test blade had a NACA 23012 section. The variation of static lift and moment coefficients with angle of attack for this section were computed from a series of transient pitch calculations, and are shown in Figure 4, together with the measured section characteristics, from Ref. 13. The aerodynamic model is seen to give nearly the correct maximum lift, but at a slightly lower angle of attack, and, as indicated from the variation of $C_{m\ c/4}$, the computed center of pressure is somewhat further aft than that of the actual airfoil section below the stall angle.

Stability in Hover

Initial calculations were performed for hovering flight, with the nominal configuration, to allow a direct comparison with the test results of Ref. 2. First, rotor speed was varied parametrically, with the collective pitch at a value well below the stall incidence. A classical bending-torsion instability was encountered at $\Omega^* \equiv \Omega R/(\omega_{\theta_0} b) = 5.3$ with $\omega_f / \omega_{\theta_0} = .803$. The variation of bending, flapping, and torsional displacements with azimuth angle at flutter onset are shown in Figure 5. By way of comparison, tests (Ref. 2) yielded classical flutter at about $\Omega^* = 7.1$ with $\omega_f / \omega_{\theta_0} = .72$.

It should be noted that since the system stability was analyzed by direct simulation, a precise point of linear instability was not computed. The values of Ω^* at onset of a linear instability, both for hover and forward flight, were obtained by successively increasing or decreasing rotor speed, in small steps, until the transient response changed from convergent to divergent, or visa versa. The maximum error in the value of flutter speed, for the results presented here, is estimated to be about three percent.

Susceptibility of the system to stall flutter was investigated next. It was found that a torsional limit cycle, at approximately the highest coupled natural frequency of the system, could be triggered for Ω^* as low as 3.4. Computed blade motions for stall flutter at Ω^* of 3.5 are shown in Figure 6.

For Ω^* below 3.4, a limit cycle could not be set up, regardless of the initial conditions or the collective pitch angle. Severe oscillations involving repeated stall and unstall could be made to occur by imposing a large initial bending deflection. However, the flapping response modulated the torsional response, and caused continuous stall and/or unstall of the blade over a significant portion of

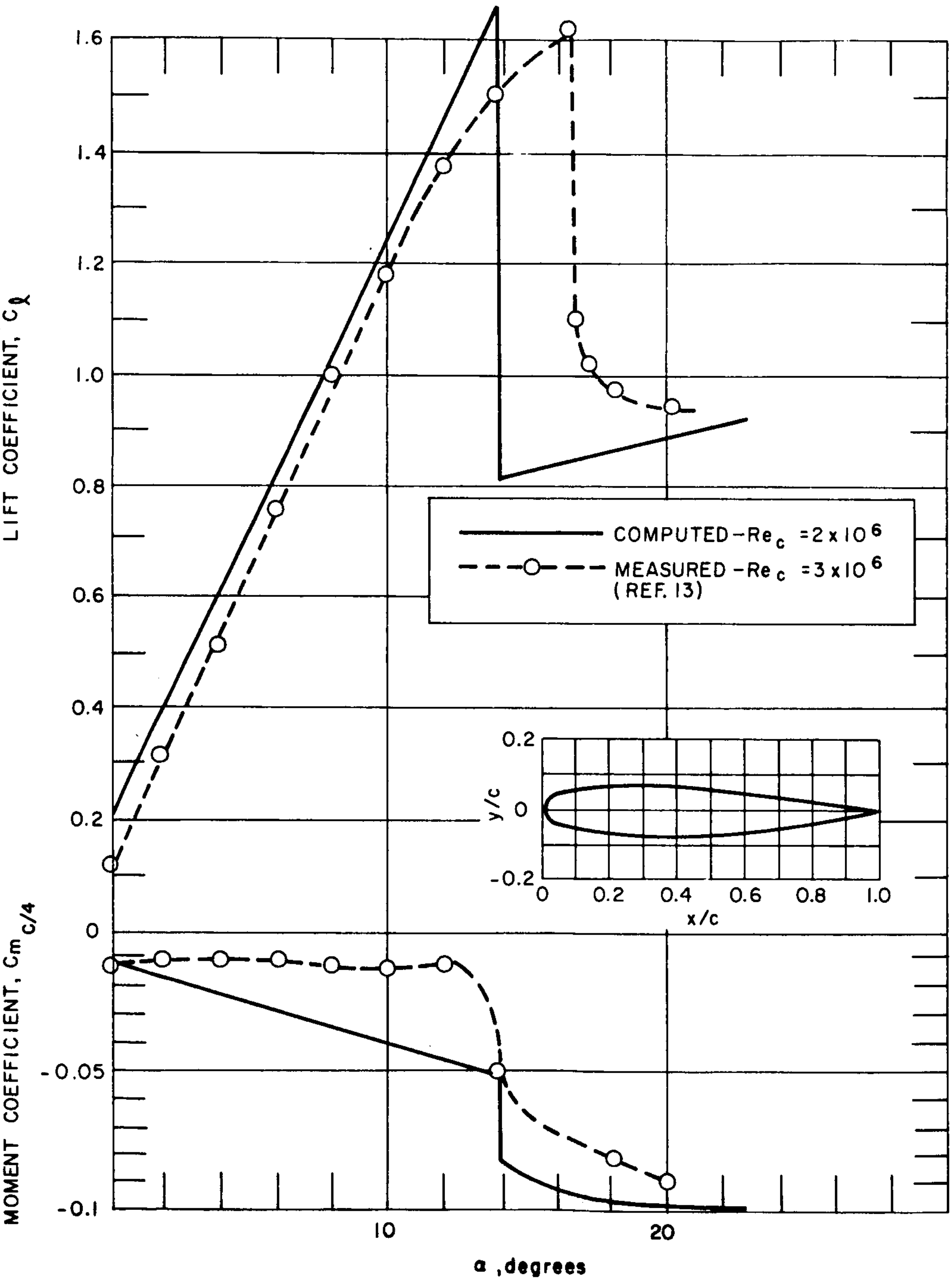


Figure 4 AIRFOIL SECTION CHARACTERISTICS FOR NACA 23012

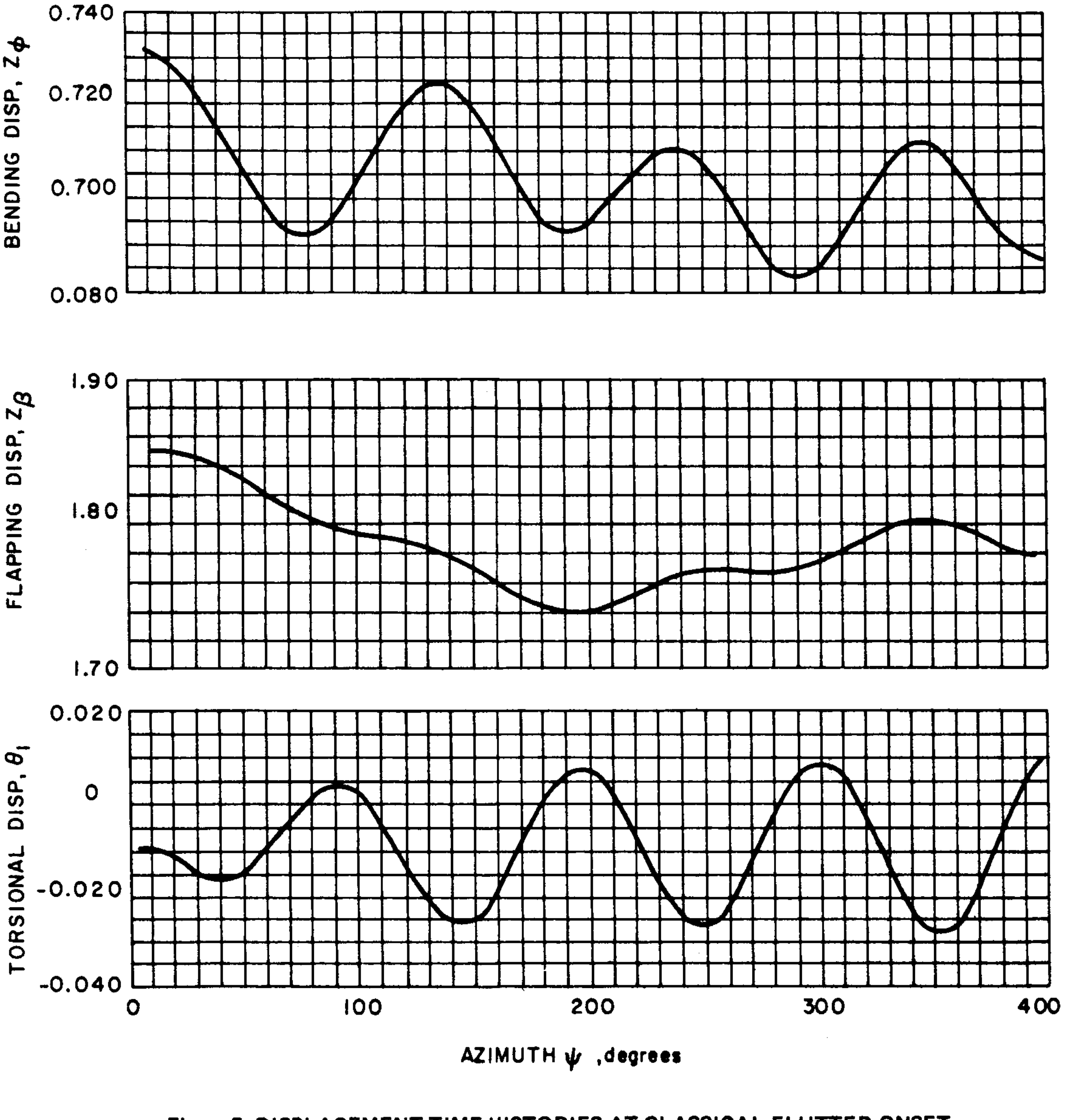


Figure 5 DISPLACEMENT TIME HISTORIES AT CLASSICAL FLUTTER ONSET
$\Omega^* = 5.3, \theta_0 = 11$ deg, $\mu = 0$

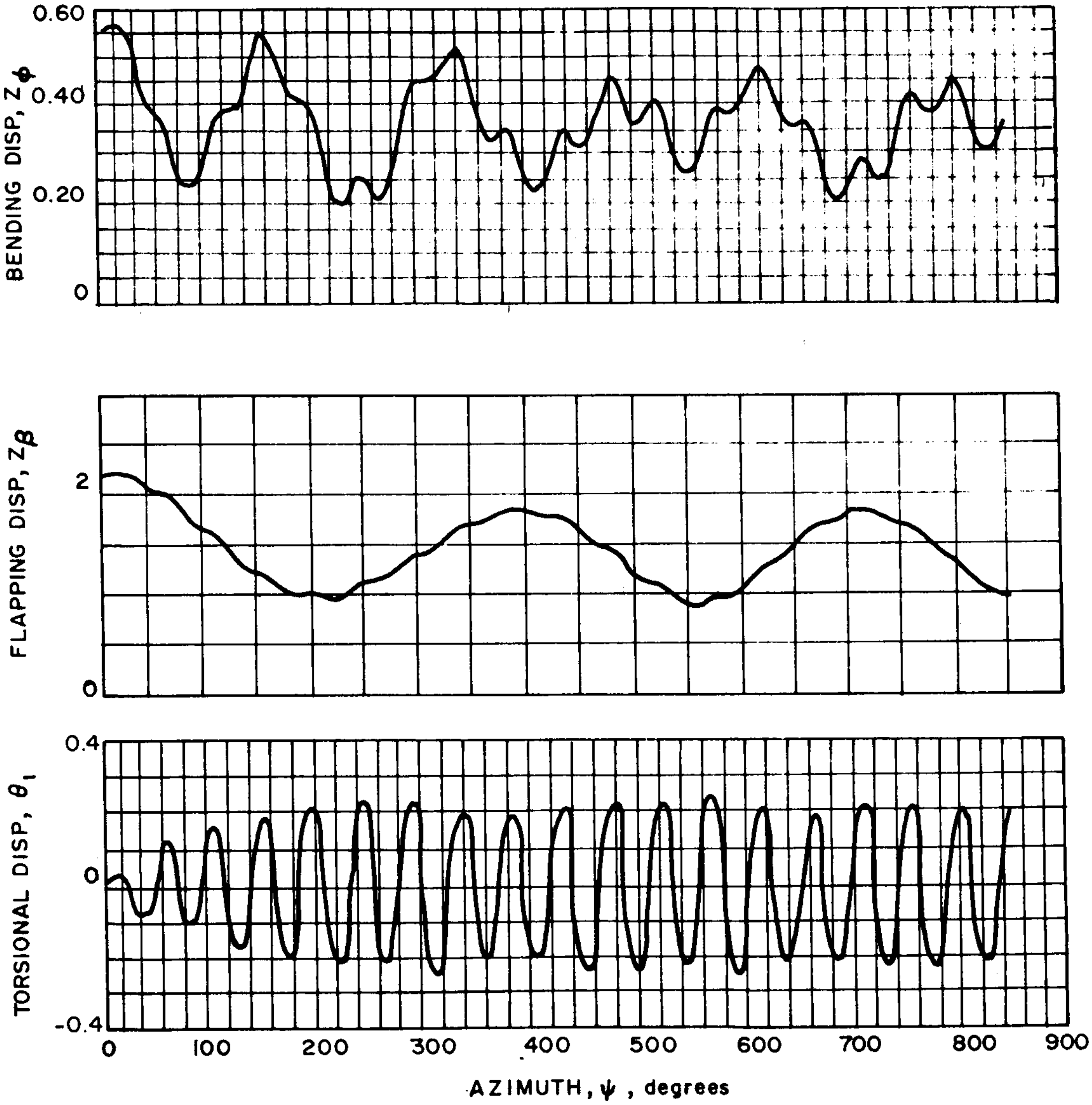


Figure 6 DISPLACEMENT TIME HISTORIES FOR STALL FLUTTER
$\Omega^* = 3.5$, $\theta_0 = 15.0$ deg, $\mu = 0$

a revolution, due to the large plunging rate generated by the flapping motion. An example of this occurrence is shown in Figure 7. Thus, while stall flutter involves only the rotational degree of freedom, the results obtained indicate that the minimum speed for its occurrence is determined by coupling with a translational degree of freedom.

Results for the hovering case are summarized in Figure 8, which compares computed and measured flutter speed and frequency, plotted against collective pitch angle. No upper limit in collective pitch angle for the occurrence of stall flutter was calculated, since that limit would depend strongly on initial conditions, and so would be arbitrary. Quantitative differences between the computed and measured stability boundaries of Figure 8 can be attributed in large part to the use of a two-dimensional aerodynamic model, which cannot precisely reproduce the aerodynamic coupling between the rotational and translational degrees of freedom.

From the basic similarity of the computed and measured stability boundaries and the character of the computed instabilities (Figures 5 and 6) it can be concluded that the aerodynamic and dynamic models formulated are capable of reproducing both classical and stall flutter as experienced by a rotor blade, and so can be employed to investigate the forward-flight problem.

Stability in Forward Flight

The nominal configuration was analyzed next for an advance ratio of .1. Computations were carried out in the same sequence as for hovering. First, the rotational speed at which classical flutter occurs was determined. Then, stall-related instabilities were investigated.

A linear bending-torsion instability of the Floquet type (Ref. 14) was encountered at $\Omega^* = 5.2$. Blade motions as a function of azimuth angle at flutter onset are shown in Figure 9. The torsional and bending displacements are seen to display the aperiodic character typical of this type of instability. The flapping motion is the steady-state response to the cyclic pitch variation.

An instability analogous to stall flutter in hover was found to occur for Ω^* as low as about 4.4, with collective pitch angle greater than 12 deg. Blade motions for $\Omega^* = 4.8$ are shown in Figure 10. The torsional displacement time history, while not strictly periodic, is nonetheless

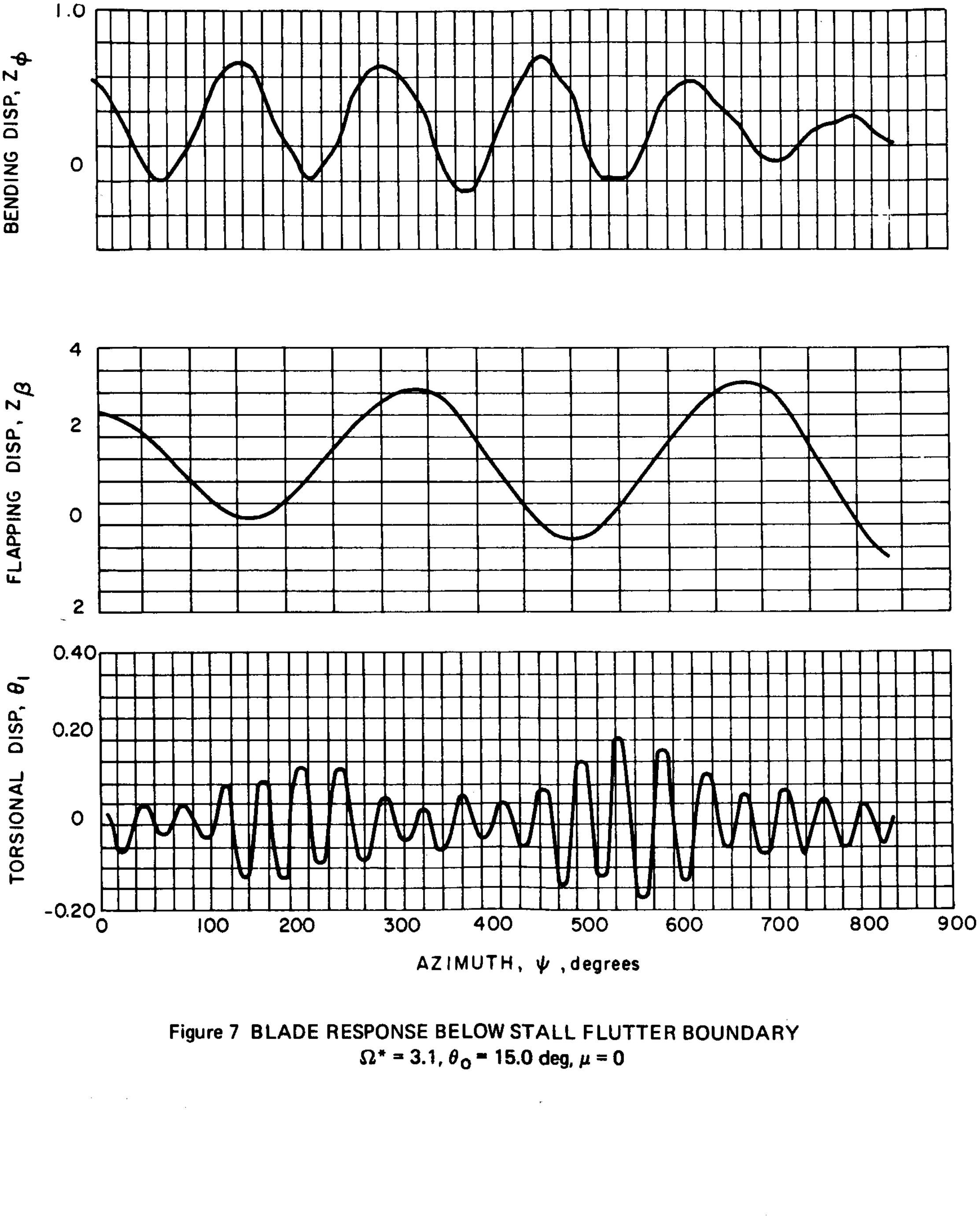


Figure 7 BLADE RESPONSE BELOW STALL FLUTTER BOUNDARY
$\Omega^* = 3.1, \theta_0 = 15.0$ deg, $\mu = 0$

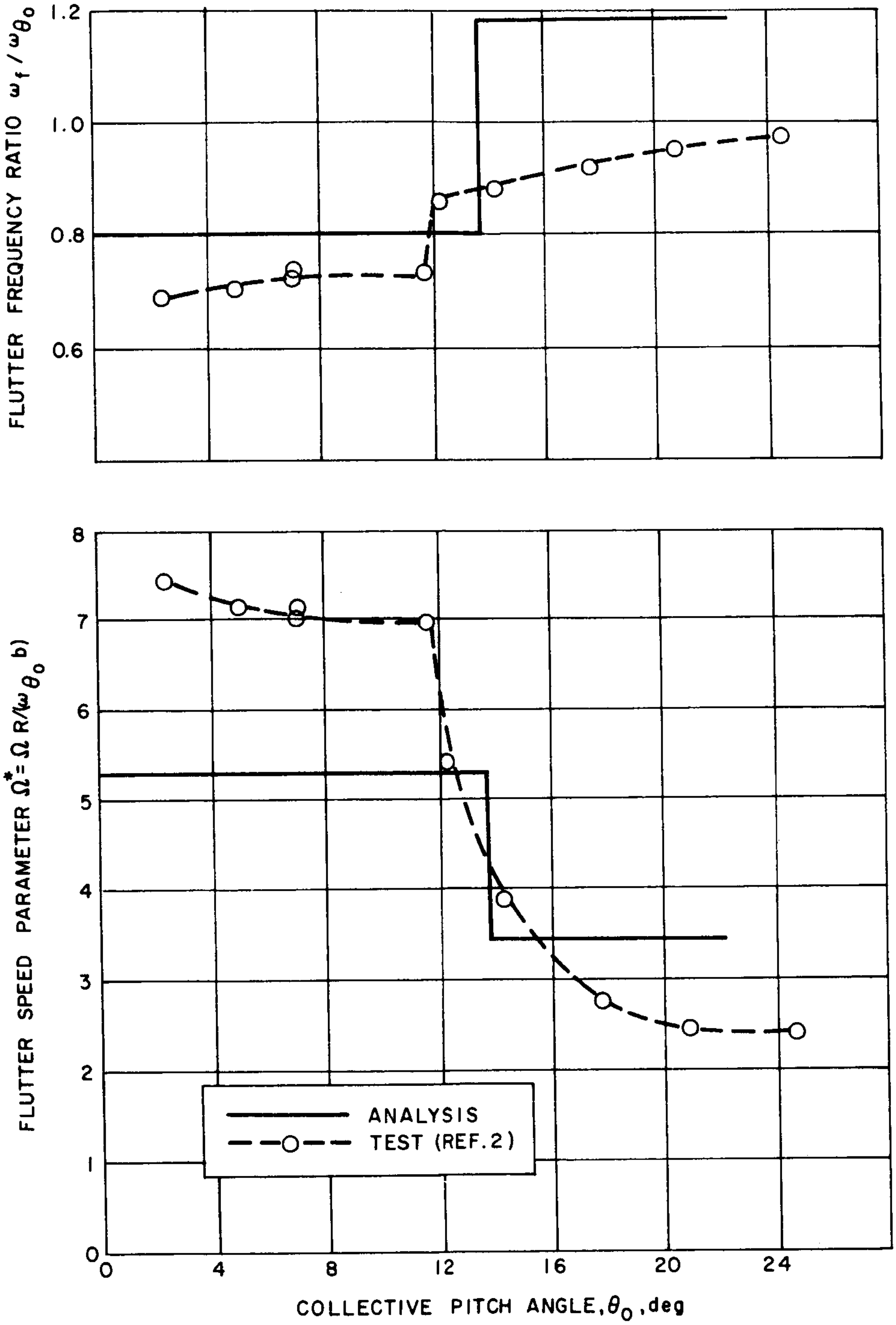


Figure 8 FLUTTER SPEED AND FREQUENCY VARIATION WITH COLLECTIVE PITCH ANGLE FOR A HOVERING ROTOR

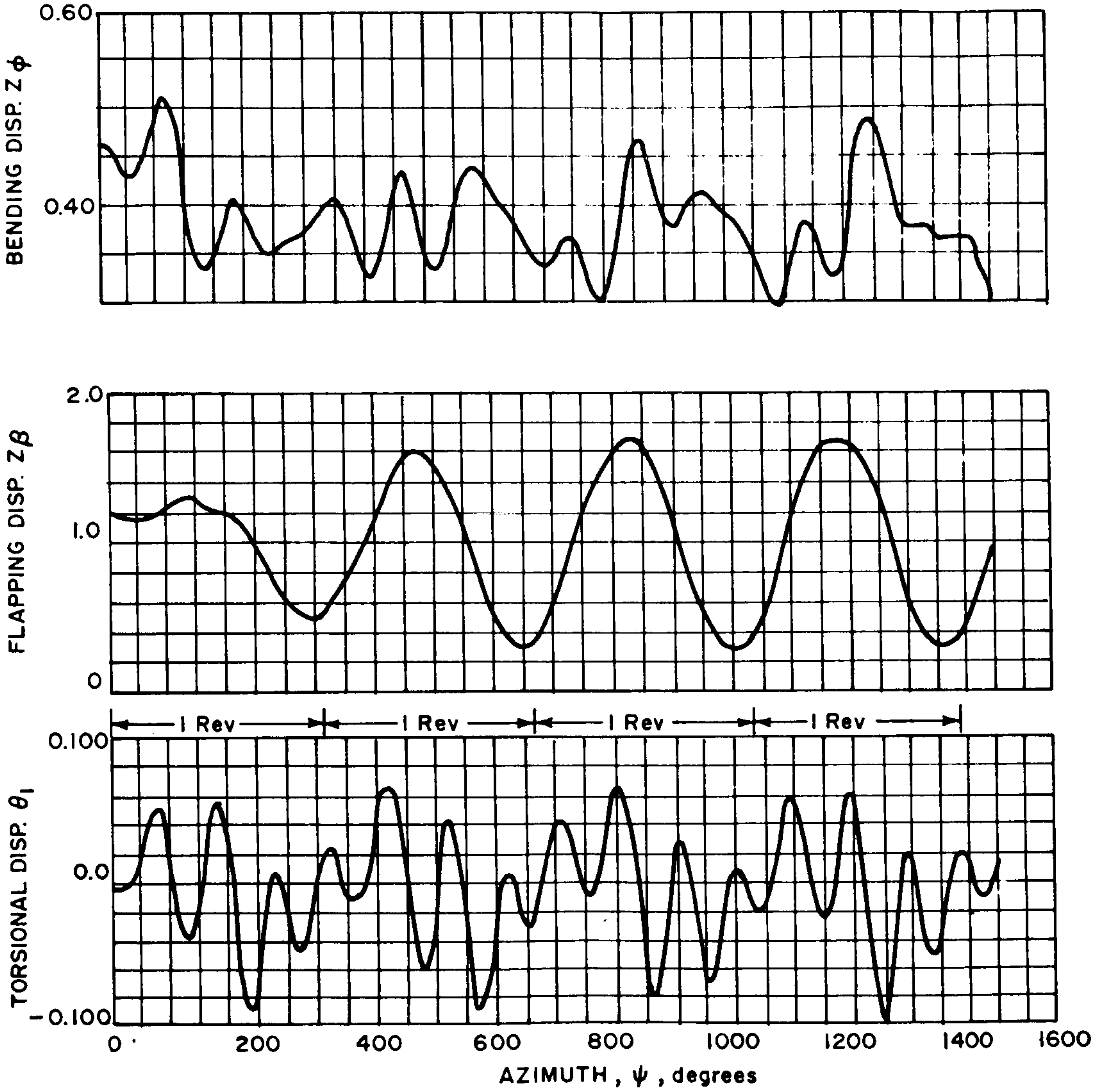


Figure 9 DISPLACEMENT TIME HISTORIES AT LINEAR INSTABILITY ONSET
$\Omega^* = 5.2, \theta_0 = 6$ deg, $\mu = 0.1$

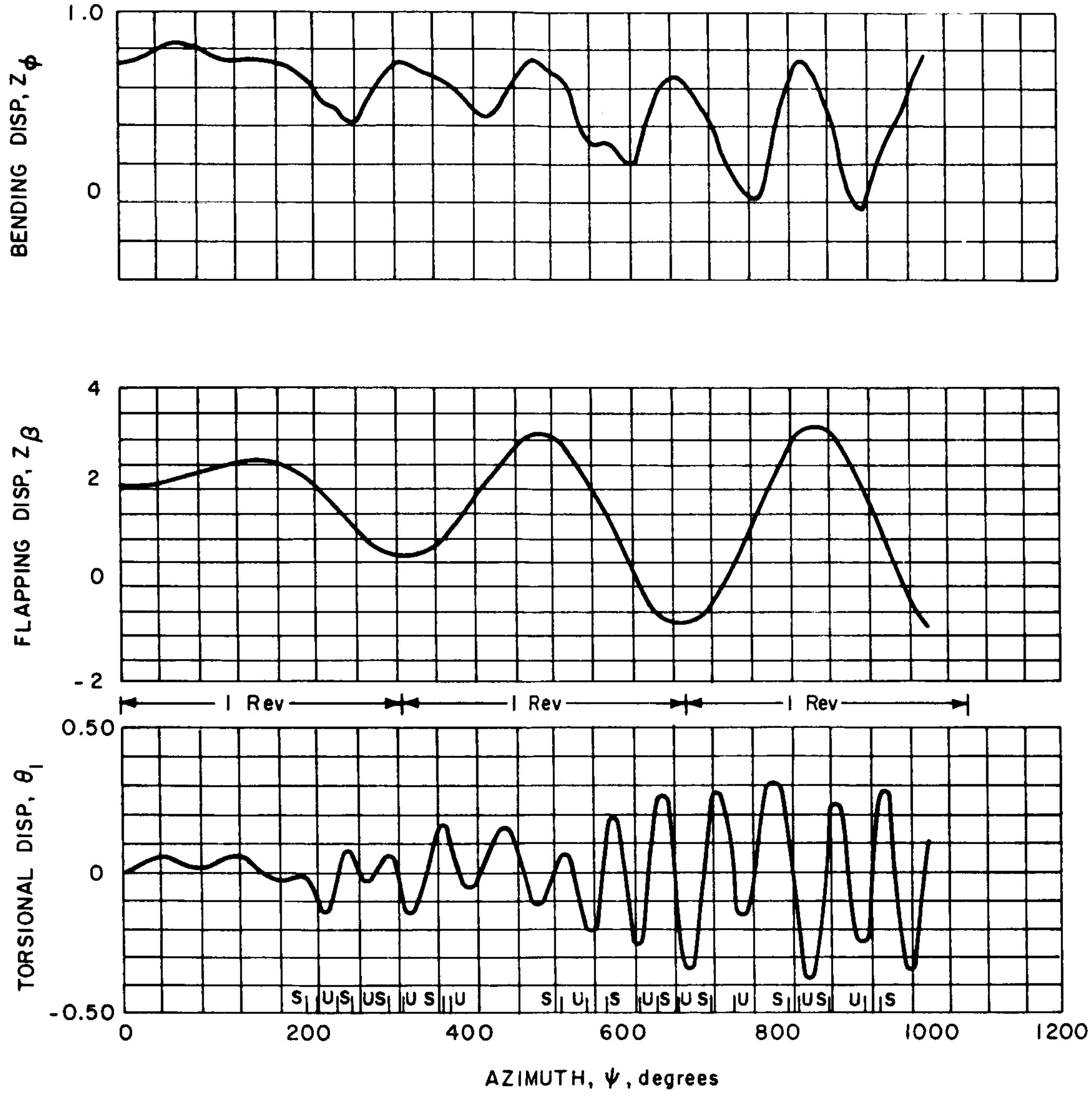


Figure 10 DISPLACEMENT TIME HISTORIES FOR STALL FLUTTER
$\Omega^* = 4.8, \theta_0 = 13$ deg, $\mu = 0.1$

brought about by successive stall and unstall. The azimuth positions at which those events occur are marked by (S) and (U), respectively, on the ψ -scale.

The blade motions for the type of instability shown in Figure 10 are not of the same character as those of particular concern in the limiting of helicopter performance, in that the excessive torsional displacements shown in Figure 10 persist over a complete revolution of the blade. The control load time history, taken from flight test (Ref. 6), shown in Figure 11 illustrates the type of stall-related blade motions usually encountered at a thrust level or forward speed near the upper limit of an aircraft. Large oscillations in the control loads, presumably deriving from blade torsional oscillations, are seen from Figure 11 to persist only between about ψ = 270 deg and ψ = 400 deg, rather than throughout a complete revolution of the blade.

A torsional displacement time history closely resembling the variation of control loads in Figure 11 was obtained for Ω^* less than 4.4, for collective pitch angles between 12 and 13 deg. Results for two typical cases are shown in Figures 12 and 13. The occurrences of stall and unstall are indicated on the abscissas. The large oscillations in torsion are clearly related to stall, but their persistence is not the result of successive stalling and unstalling, as would be the case for true stall flutter. The blade appears to be responding to the sudden changes in aerodynamic moment at stall onset and unstall, as can be seen by comparing the variation of moment coefficient shown in Figures 12 and 13 with that of torsional displacement, and noting the azimuth positions at which stall and unstall occur. There is some cyclic stall-unstall within the stall zone evident in the results, particularly at the higher rotor speed (Ω^* = 4.15, Figure 13). However, the major contributors to the oscillations appear to be the initial and final pulses associated with stall and unstall upon entering and leaving that zone. There are, in general, two cycles of torsional oscillation of excessive amplitude after the blade unstalls the last time on a given revolution. The response can be regarded as transient, on a localized time scale, or forced, when viewed on a scale of several rotor revolutions. The severity of the response is apparently due in part to the suddenness of load changes at stall and unstall, and partly to the relative lack of aerodynamic damping in pitch, particularly when the blade is not stalled.

If the collective pitch angle is increased, the blade does undergo stall flutter, as seen from the time history plotted in Figure 14. These results are for the same rotor

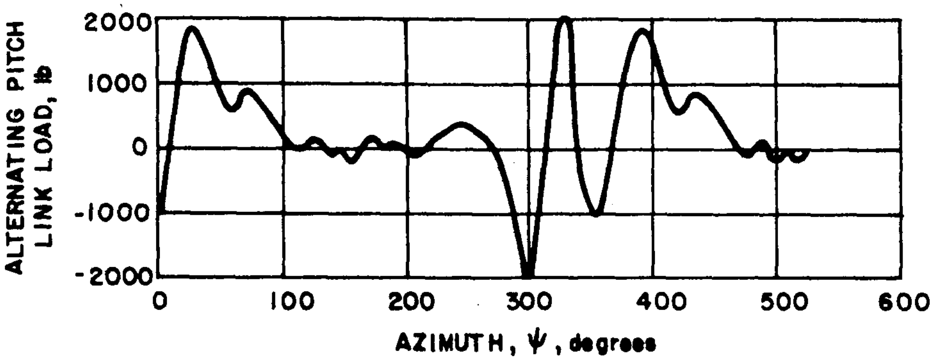


Figure 11 VARIATION OF PITCH LINK LOAD IN FLIGHT TEST OF CH-47 AT 123 KNOTS (from Ref. 6)

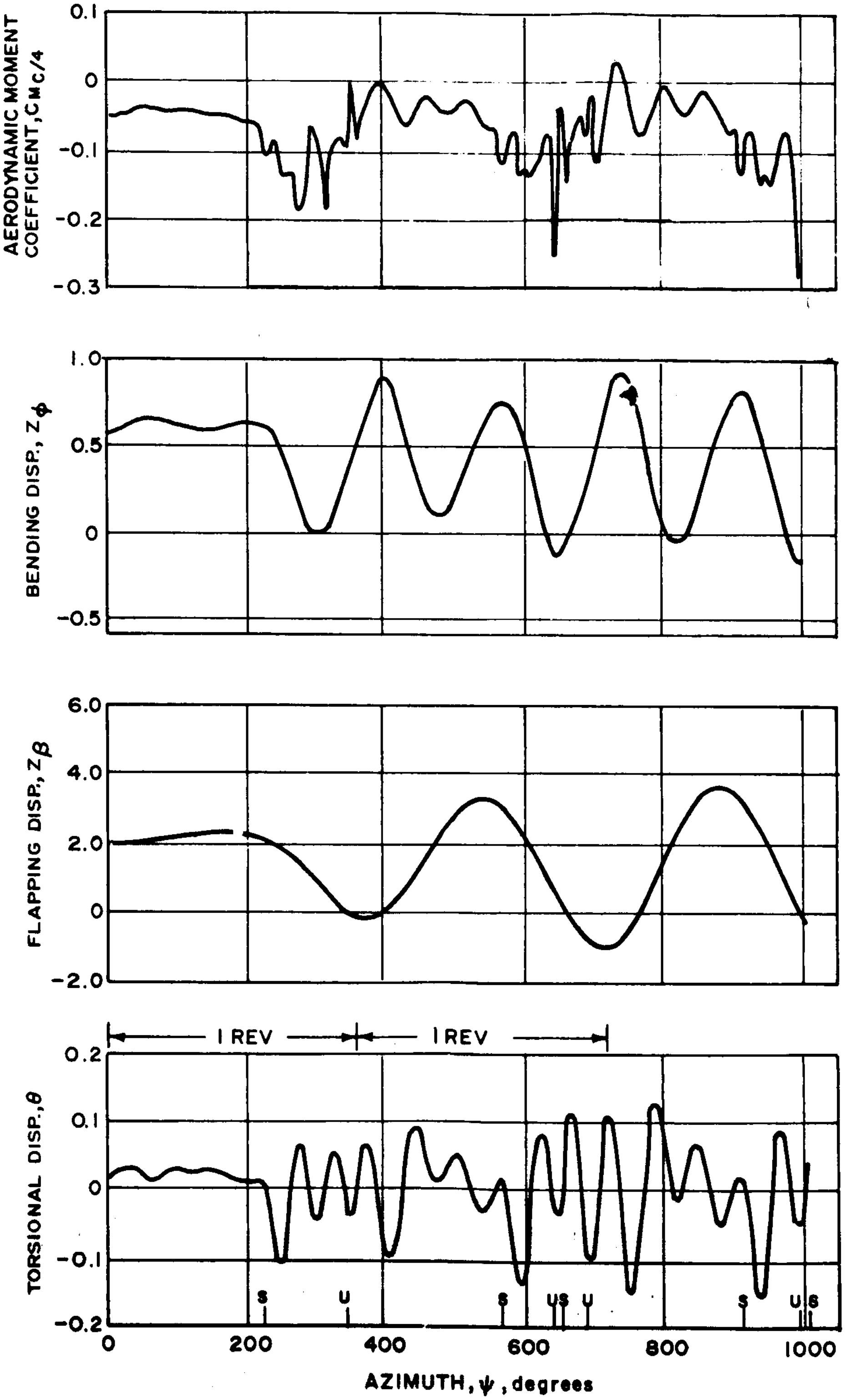


Figure 12 DISPLACEMENT AND MOMENT TIME HISTORIES FOR EXCESSIVE TORSIONAL RESPONSE

$\Omega^* = 3.89, \theta_0 = 12$ deg, $\mu = 0.1$

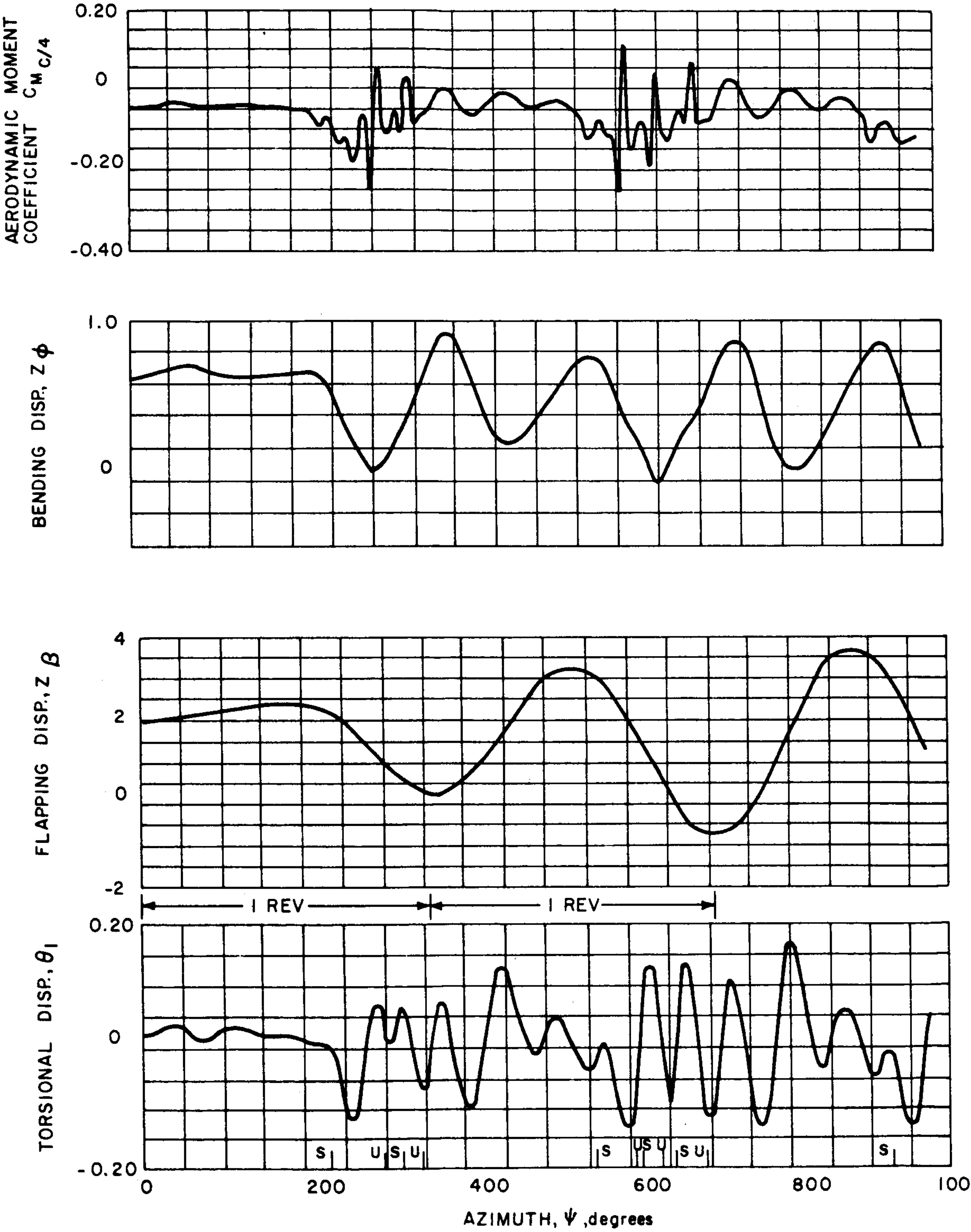


Figure 13 DISPLACEMENT AND MOMENT TIME HISTORIES FOR EXCESSIVE TORTIONAL RESPONSE
$\Omega^* = 4.15, \theta_0 = 12$ deg, $\mu = 0.1$

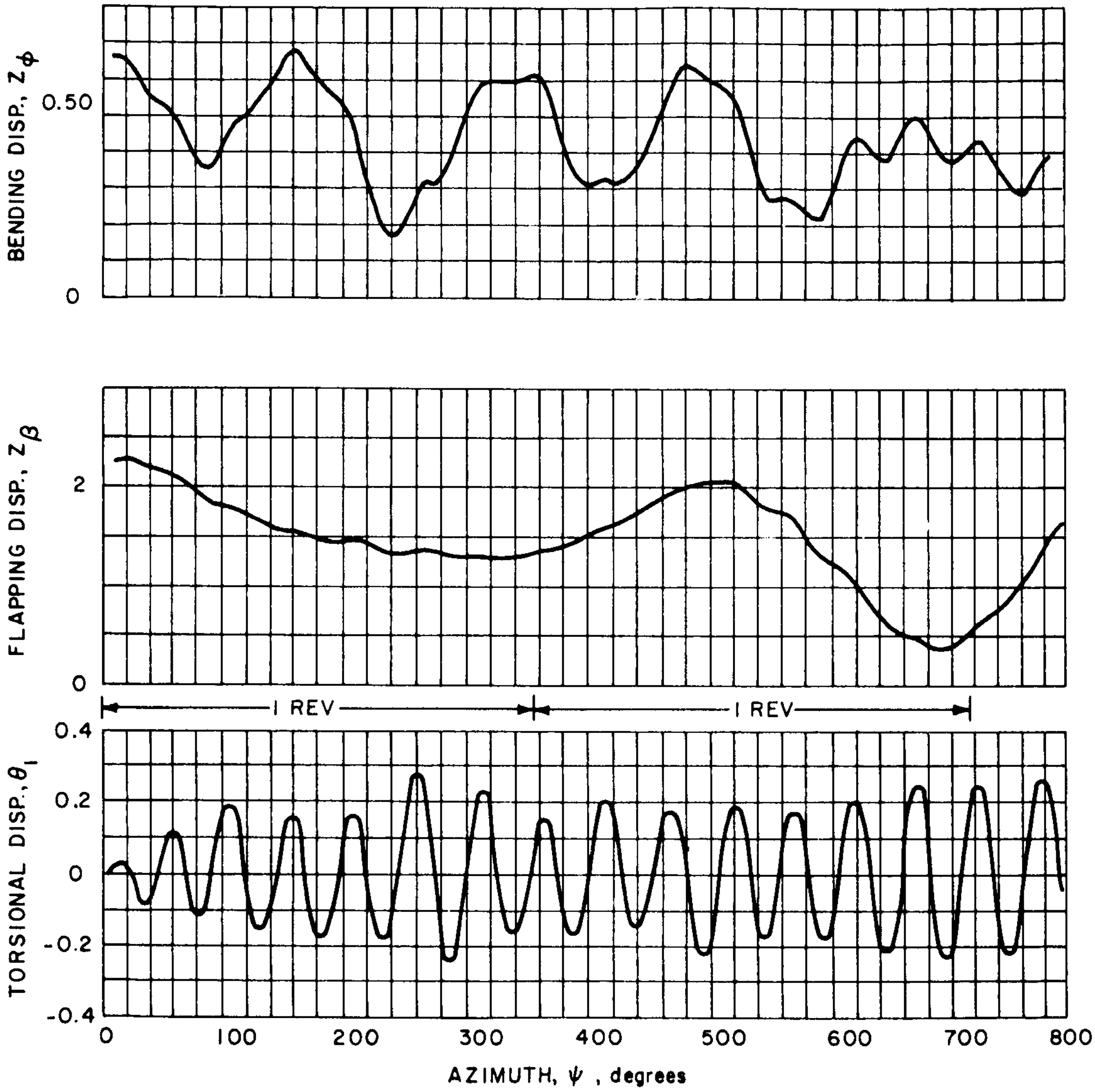


Figure 14 DISPLACEMENT TIME HISTORIES FOR STALL FLUTTER AT LOW ROTOR SPEED $\Omega^* = 3.89, \theta_0 = 14.3$ deg, $\mu = 0.1$

speed as those of Figure 12, but with θ_0 increased from 12 deg to 14.3 deg. Successive stall and unstall persists over the whole revolution of the blade for this case.

It could be argued that the blade torsional oscillations of Figures 12 and 13 are still a manifestation of stall flutter, even though successive stall and unstall is not taking place, since the aerodynamic moment can undergo unstable variations when the blade remains stalled throughout a cycle (Ref. 4). It may, in fact, be the case that the large deflections do result partly from that effect, so choosing to term them as simply a response may be somewhat misleading. On the other hand, the solutions are distinctly different from what is definitely stall flutter obtained both in hover (Figure 6) and in forward flight (Figures 10 and 14) so that label would seem to be even less appropriate. Further, the persistence of the oscillations after exit from the stall zone is clearly symptomatic of a response, so, for lack of a more precise term, solutions of the type shown in Figures 12 and 13 are identified in what follows as excessive response.

Linear Stability Boundaries

The value of Ω^* at the onset of linear instability was determined for the three configurations considered, for advance ratios of 0, .1, .2, and .3. The effects of advance ratio and torsion-bending frequency ratio on linear stability are shown in Figure 15, where Ω^* is plotted against μ for two different frequency ratios. Increasing advance ratio is seen to cause some decrease in flutter rotational speed, with most of the decrease occurring between advance ratios of .1 and .2. The substantial decrease in frequency ratio, from 3.69 to 2.5, caused only about a 4 percent reduction in flutter speed over the range of advance ratios considered. The insensitivity to frequency ratio can be attributed to the large chordwise mass imbalance, which produces the same effect in classical binary flutter of a wing (Ref. 15).

The effect of chordwise mass imbalance on linear stability is shown in Figure 16, where Ω^* at flutter onset is plotted against μ for values of x_m of .216 and .108 semichords. As one would expect, the reduction in x_m, and hence in the coupling between bending and torsion, causes a substantial increase in the flutter rotational speed.

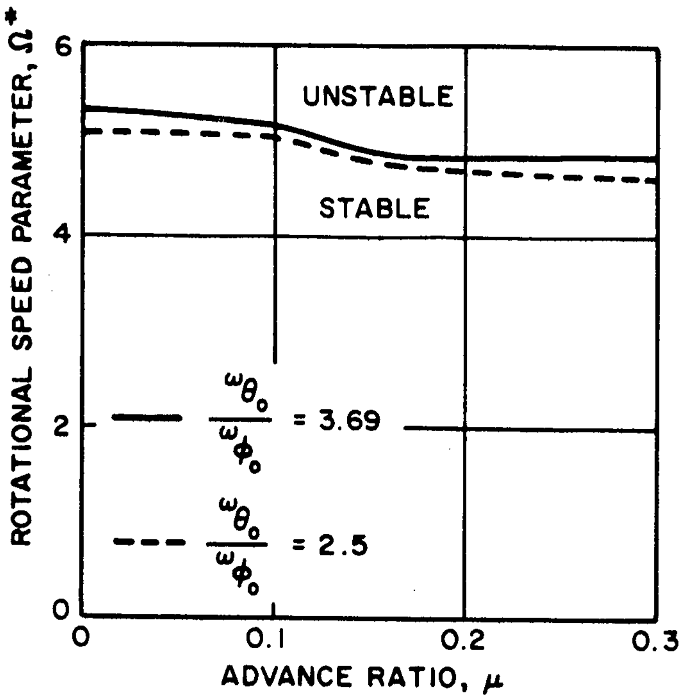


Figure 15 EFFECT OF ADVANCE RATIO AND TORSION-BONDING FREQUENCY RATIO ON LINEAR STABILITY - Xm/b = 0.216

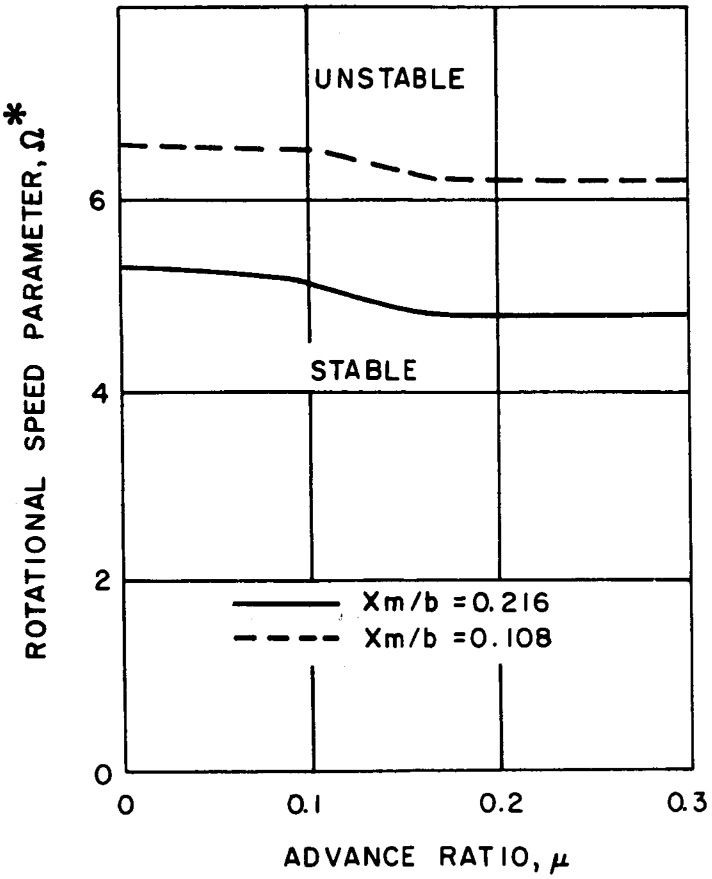


Figure 16 EFFECT OF Xm ON LINEAR STABILITY - $\omega_{\theta_0}/\omega_{\phi_0}$ = 3.69

Stall Flutter and Response Boundaries

The effect of forward speed on stall-related instabilities for the three configurations was investigated by systematically varying the collective pitch angle and advance ratio, with Ω^* equal to 3.89. In order to relate the results to rotor performance, a mean lift coefficient $\bar{C}_L$ is defined, according to

$$\bar{C}_L \equiv \frac{\bar{l}}{\rho\, \Omega^2 R^2 b}$$

where $\bar{l}$ is the time-averaged lift per unit span at the aerodynamic reference radius. This coefficient is, to a good approximation, directly proportional to the thrust coefficient (see Ref. 16). The two-dimensional aerodynamic model does not provide a good measure of $\bar{C}_L$ when the rotor is partially stalled, so $\bar{C}_L$ was computed assuming it varies linearly with the collective pitch angle, using the formula

$$\bar{C}_L = a(\mu)(\theta_o + .0217)$$

The slope a and zero-lift collective pitch angle of -.0217 rad were obtained from calculations of $\bar{C}_L$ for the nominal configuration with stall precluded. The variation of a with μ is shown in Figure 17.

The results obtained for the nominal configuration are summarized in Figure 18 as a plot of $\bar{C}_L$ vs μ. As thrust is increased at a given μ, the rotor is seen to first encounter a region of excessive response, of the type discussed previously, and then, for μ of .2 or less, a region where stall flutter occurs. Increasing advance ratio has the effect of suppressing the tendency for stall flutter. At μ = .2, stall flutter occurs at $\bar{C}_L$ = .85, but a further increase in $\bar{C}_L$ results in excessive response again. At μ = .3 a limit-cycle type of oscillation could not be triggered at all. As a result, stall flutter is confined to a region somewhat as indicated by the shaded area in Figure 18.

The suppression of stall flutter at high advance ratio is apparently caused by an effect similar to the one encountered at low rotor speed in hover, whereby the flapping motion prevented a limit cycle from occurring. This can be seen from the blade motions obtained for μ = .3 and

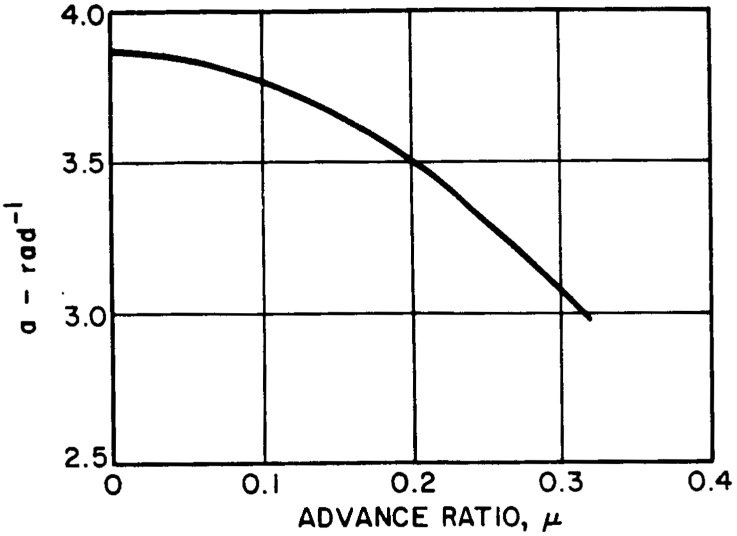


Figure 17 VARIATION OF $a = d\bar{C}_L/d\theta_0$ WITH ADVANCE RATIO

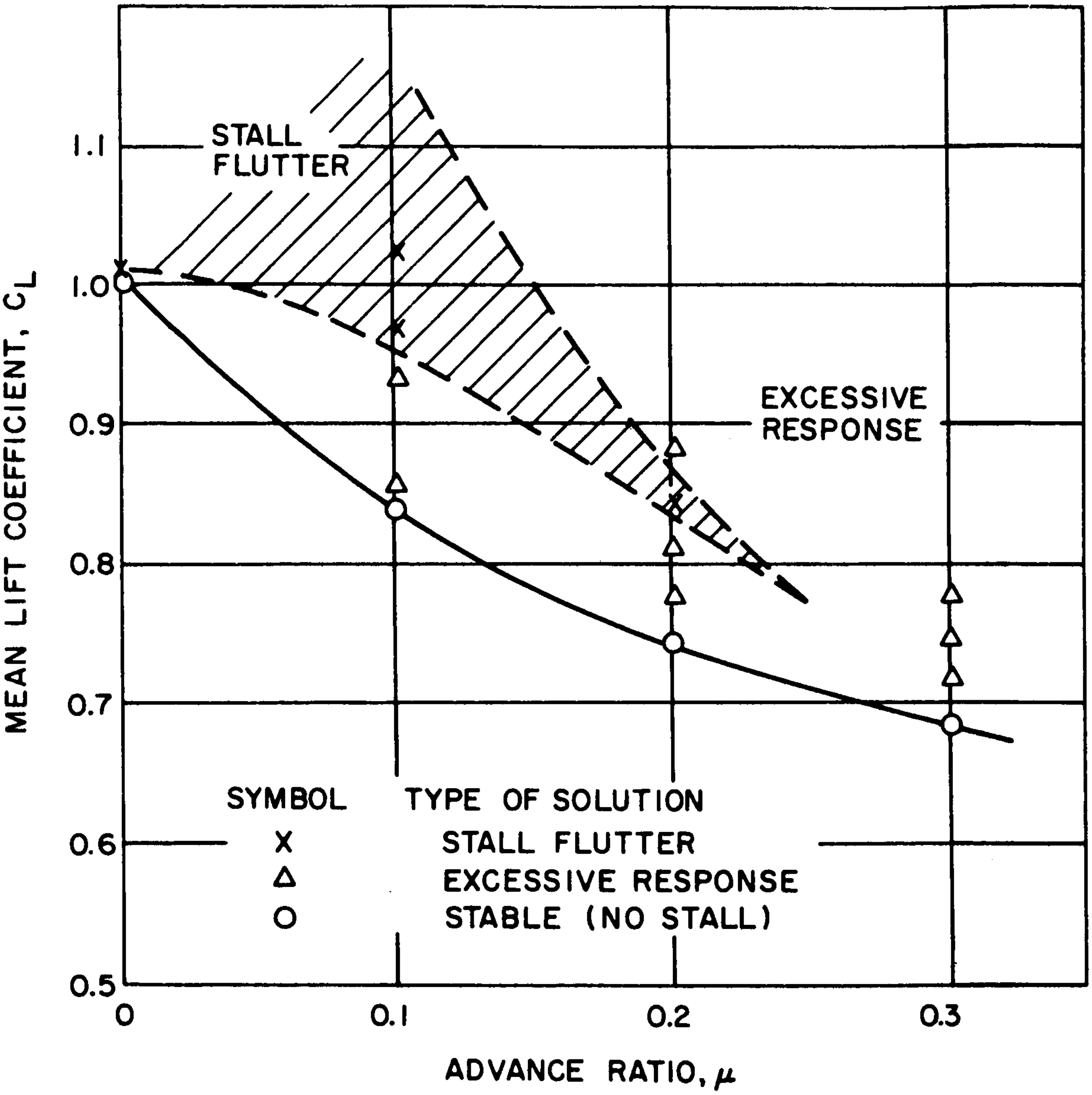


Figure 18 STALL STABILITY BOUNDARIES FOR $\Omega^* = 3.89$, $\omega_{\theta_0}/\omega_{\theta_0} = 3.69$ AND $Xm/b = 0.216$

$\bar{C}_L$ = .78, plotted in Figure 19. On the first revolution, as the blade enters the stall zone on the retreating side, it appears that a limit cycle is being set up, with repeated stall and unstall occurring. However, at about ψ = 420 deg, the flapping motion has built up in response to the large cyclic pitch changes, producing a negative plunging rate sufficient to keep the blade unstalled over the remainder of its passage on the advancing side. Then, when the blade again enters the stall zone, the large positive flap-induced plunging rate precludes unstall until exit from the stall zone at about ψ = 670 deg. As a result, the blade subsequently undergoes excessive torsional response, rather than stall flutter.

The effect of torsion-bending frequency ratio on stall-related instabilities can be seen from Figure 20, where $\bar{C}_L$ is plotted against μ for $\omega_{\theta_0}/\omega_{\phi_0}$ = 2.5. No instance of excessive torsional response occurred with this configuration for an advance ratio of .2 or less. Instead, limit-cycle type oscillations were set up, with almost no evidence of suppression by the flapping motion, even at relatively high values of $\bar{C}_L$ with μ = .2. At μ = .3, however, only excessive response was obtained, similar to the results for $\omega_{\theta_0}/\omega_{\phi_0}$ = 3.69.

The marked deterioration in stability at the lower frequency ratio is apparently associated with the lessened linear stability of the system. The configuration with x_m/b = .108, which is more stable, in the linear sense, than the nominal one, exhibited a trend opposite to the one resulting from a decrease in frequency ratio. The results for the smaller mass center offset, shown in Figure 21, are similar to those of the nominal configuration, Figure 18, but the region in which stall flutter occurs is somewhat reduced, there being no occurrence of stall flutter at an advance ratio of .2. Also, the amplitude of the torsional oscillations in the region of excessive response is considerably reduced, as evidenced by comparing the blade motions plotted in Figure 22, which are for μ = .1, $\bar{C}_L$ = .95 and x_m/b = .108, with those of the nominal configuration plotted in Figure 12.

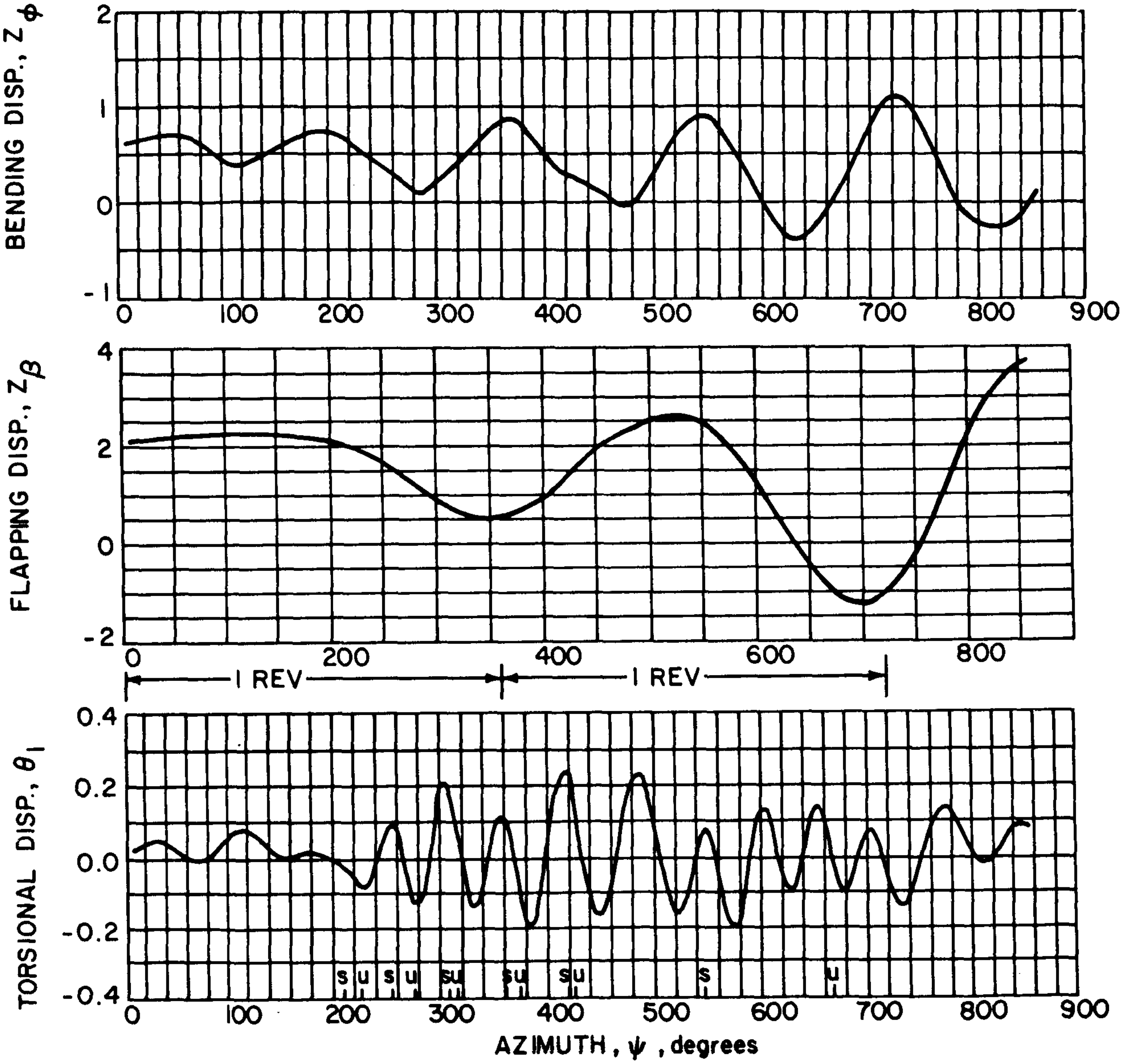


Figure 19 DISPLACEMENT TIME HISTORIES AT HIGH ADVANCE RATIO – $\Omega^* = 3.89$, $\bar{C}_L = 0.78$, $\mu = 0.3$

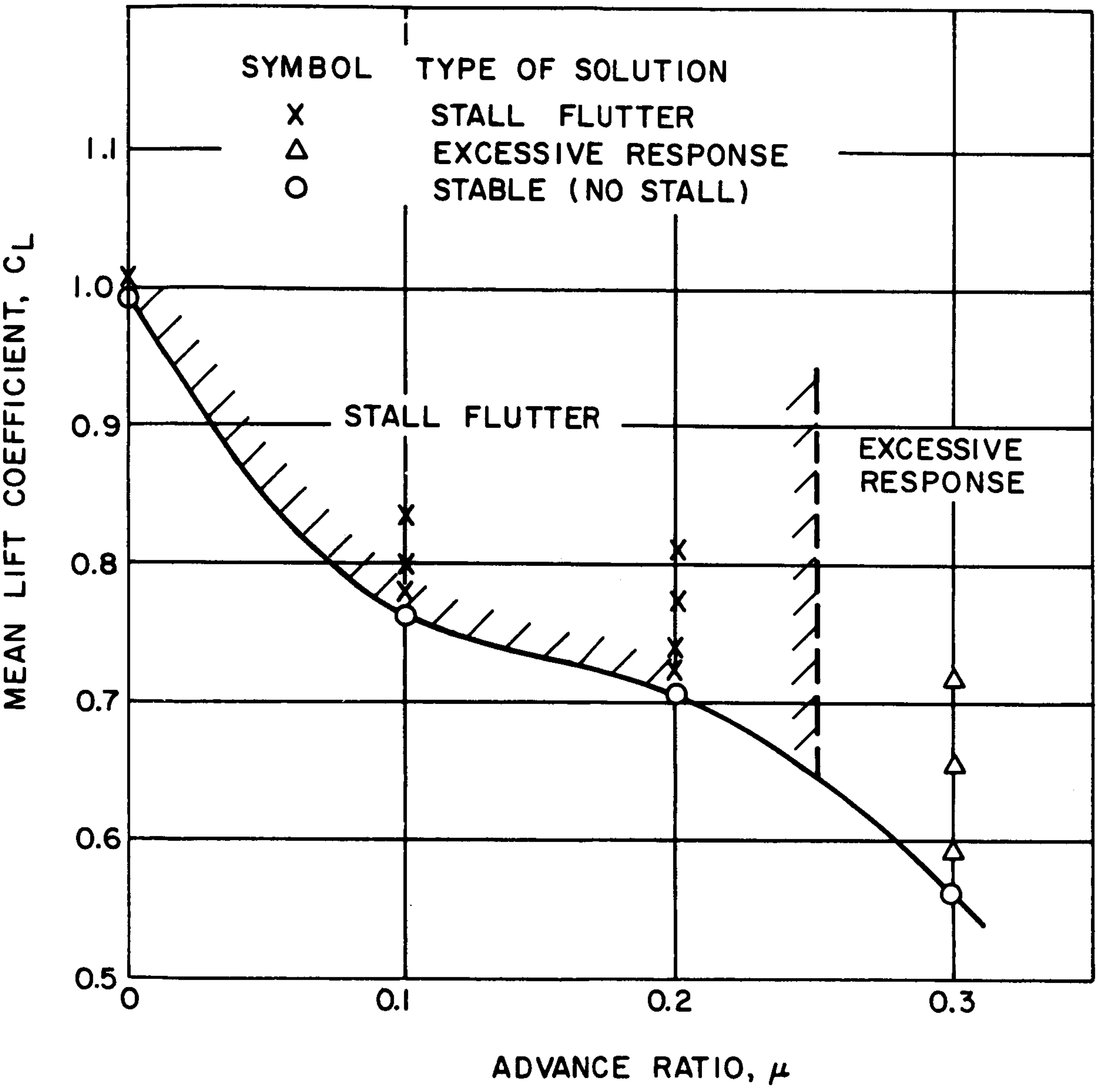


Figure 20 STALL STABILITY BOUNDARIES FOR $\Omega^* = 3.89$, $\omega_{\theta_0}/\omega_{\phi_0} = 2.5$ AND $Xm/b = 0.216$

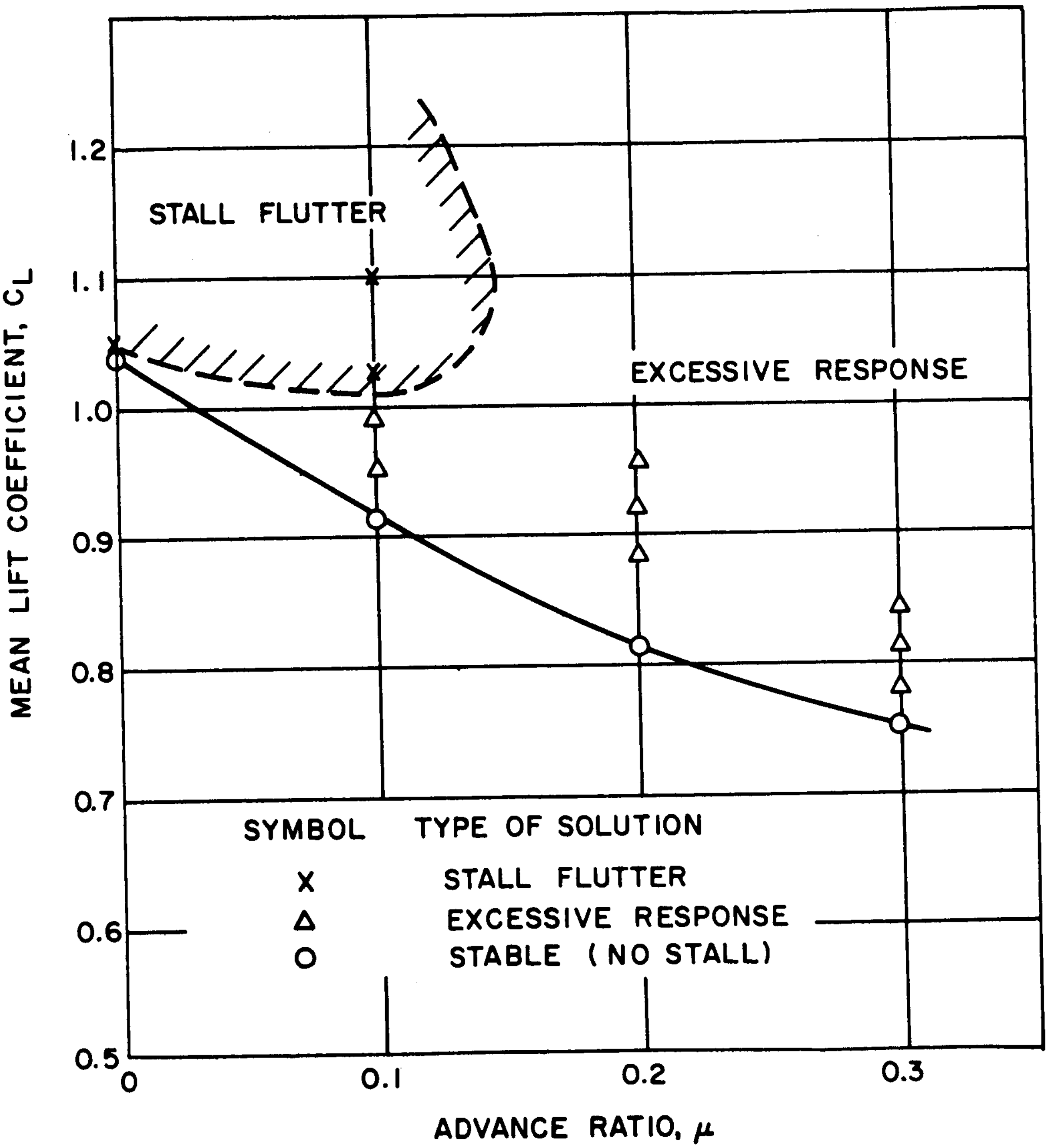


Figure 21 STALL STABILITY BOUNDARIES FOR $\Omega^* = 3.89$, $\omega_{\theta_0}/\omega_{\phi_0} = 3.69$ AND $Xm/b = 0.108$

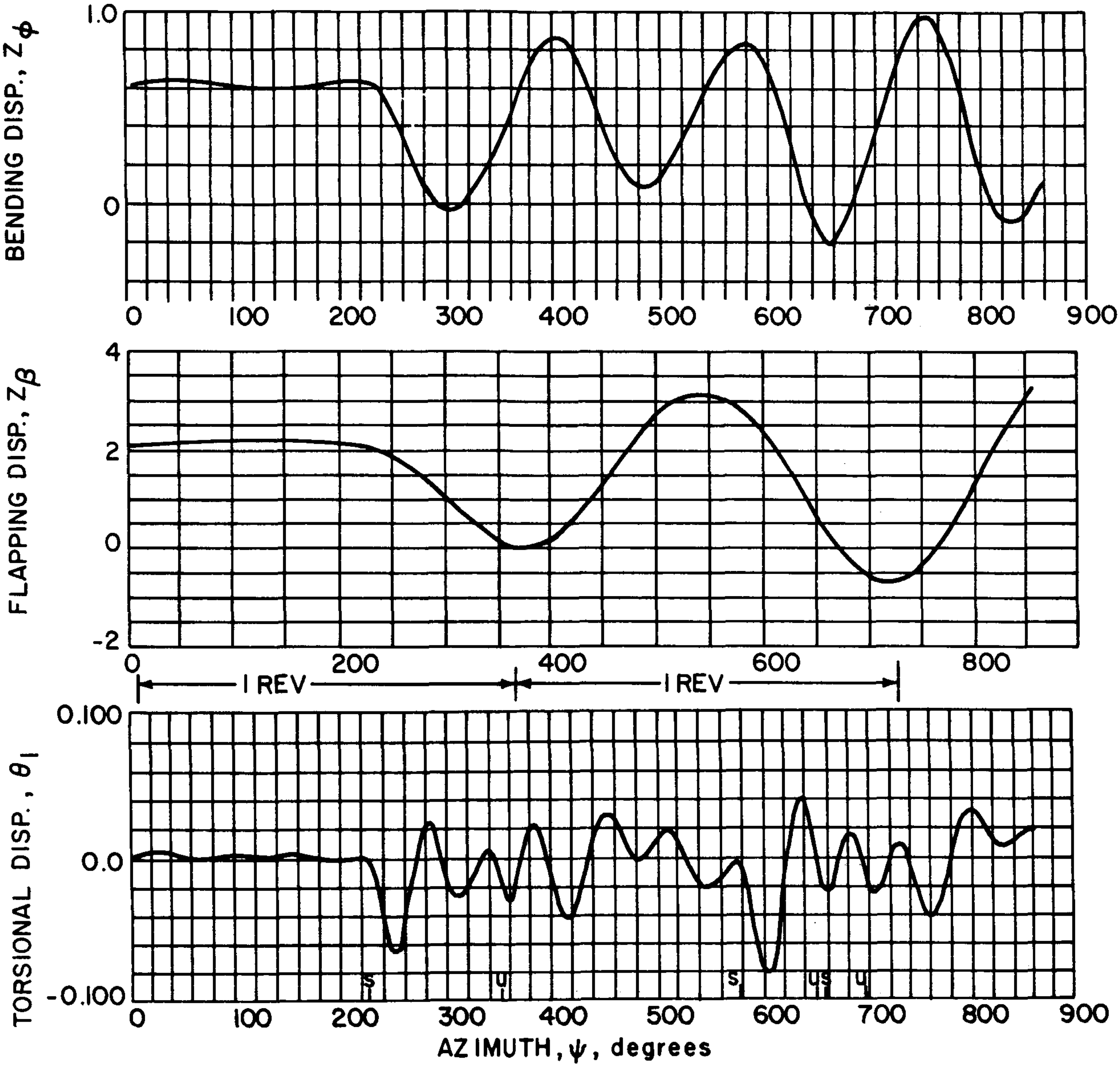


Figure 22 DISPLACEMENT TIME HISTORIES FOR EXCESSIVE TORSIONAL RESPONSE. $\Omega^* = 3.89$, $\bar{C}_L = 0.95$, $\mu = 0.1$, AND $Xm/b = 0.108$

CONCLUSIONS

An analysis has been performed of the aeroelastic stability of a helicopter rotor blade in hovering and forward flight. An analytical model of an airfoil undergoing unsteady stall and an elastomechanical representation including flapping, flapwise bending and torsional degrees of freedom were employed in the study. The following conclusions can be drawn from the results obtained.

1. Analysis of aeroelastic stability for a hovering rotor demonstrated that the aerodynamic and dynamic representations developed are capable of reproducing classical and stall flutter.

2. While stall flutter is an instability involving a single rotational degree of freedom, the minimum rotational speed for its occurrence, in hover, is determined from coupling with a translational degree of freedom.

3. In forward flight, the rotor can undergo a linear instability analogous to classical flutter and a stall-induced flutter which, while not manifested by a strictly periodic limit cycle, has the same basic mechanism for its occurrence as stall flutter of a hovering rotor.

4. The large stall-related torsional oscillations which limit forward speed and thrust are primarily the response to the rapid changes in aerodynamic moment which accompany stall and unstall, rather than the result of an aeroelastic instability.

5. Linear stability is relatively insensitive to advance ratio for advance ratios as large as .3.

6. While excessive response due to stall occurs at high advance ratio, stall flutter is precluded by the large flap-induced plunging rates.

7. The severity of stall-related instabilities and response depends to some extent on linear stability. Increasing linear stability lessens the susceptibility to stall flutter and reduces the magnitude of the torsional response to stall and unstall.

APPENDIX A

PROGRAM LISTING

APPENDIX A

PROGRAM LISTING

A listing of the FORTRAN coding of the computer program follows. The program was written in FORTRAN IV for use on an IBM 360/75 computer.

```
C                                                                      MAIN   2
C   PROGRAM TO ANALYZE UNSTEADY AIRFOIL STALL                          MAIN   3
C                                                                      MAIN   4
      CCMMON /BL1/       NTIME, NDIMC , ISTD
        CCMMON  /CLCMBL / CLVB ,  CMVB , CMPAVB
C                                                                      SETUPS17
      COMMON /INPTVB/    FTVB(64),  FPVB(64),  FPPRVB(64),  DIDRVB(64), SETUPS18
     A     XMVB(64),     DELVB,     XMUVB,     FOVB,   XMUAVB,          SETUPS19
     B     ATOVB,        ATCVB,      ATSVB,      ROVB,        RVB(64),  SETUPS20
     C     MVB(64),      NVB                                            SETUPS21
C                                                                      SETUPS22
      COMMON /INPUTS/    NSBL,      NZ,        NOFF,      NGAM,      NSIG,     SETUPS23
     A        NCOI,      NCORD,     LOWER,     MSTOP,     MAXT,      MOTR,     SETUPS24
     B        NOTBL,     INDV,      ELSIG,     DXI,       REB,       RDBB,     SETUPS25
     C        FRZ,       ARR,       AMPLU,     FREQU,     ALPH1,     ALPH2,    SETUPS26
     D        HEAVE,     AROT,      FREQF,     PHIH,      NY,        RY1,      SETUPS27
     E        DRY,       Y(100),    TEST,      UPRIM,     XU(30),    YU(30),   SETUPS28
     F        XL(30),    YL(30),    ER1,       ER2,       ER3,       BD3R,     SETUPS29
     G        RRDBR                                                     SETUPS30
     H,   CMPA, CMPAS, BARG, EM1, HVOR, NVOR, SSPA, SVOR, TORF, X1VOR
     I, PLOTOP, PSILOW, PSIUP
     J , NOUT
        COMMON/ ZZZ/ Z(3)
C                                                                      SETUPS31
C
C     DIMENSION USAV(300,100) ,SCALS(300)                              MAIN   5
      DIMENSION USAV(1   ,1  ) ,SCALS(300)                             MAIN   5
      DIMENSION CAMBR(24) ,THICK(24)                                   MAIN   6
      DIMENSION XGAM(30),XSIG(100),XSIGA(100),XSIGB(100),XC(300),X(300),MAIN   7
     1SBL(300),XBSIG(100)                                              MAIN   8
      DIMENSION ACAP(30,3),BCAP(100,3),ASZ(30),AS(30,30),BS(30, 30),ASHZMAIN   9
     1(100),ASH(30,30 ),BSH(30,30  ),AR(30),ARH(100),UE(300,3)         MAIN  10
      DIMENSION ALAM(30),VZIP(30),FPRES(100),GAMAW(1000),XIW(1000)     MAIN  11
      DIMENSION BLAM(30),FLAM(10),XFLAM(10)                            MAIN  12
      DIMENSION SCALE(300,2),U(1,1,1    ),UC(100,3),V(100,2)           MAIN  13
     1 , P(200,7)
C
C
      DOUBLE PRECISION CMAT(60,60  ),RMAT(130)                         MAIN  15
C
C
        DATA IN, MOUT, NF/ 5,6, 24/
      DATA PI,TIME,UINF,RENEL,USTOP/3.14159,0.,1.,4.75E4,2.8/          MAIN  18
      DATA  FLAM           /1.75,1.75,1.724,1.527,1.354,1.,.663,.452,.25MAIN  19
     14,.21/                                                           MAIN  20
      DATA  XFLAM          /-100.,-11.26,-7.01,-3.48,-1.766,0.,1.888,4.MAIN  21
     103,6.77,7.19/                                                    MAIN  22
      DATA  DEGRES /1.74 53292 51994 330D-2/                           SUPPL 38
C
C
      EQUIVALENCE (CMAT(1),USAV(1)),(ASH(1),SCALS(1))                  MAIN  16
C
C
C
C IF ISTD =1     TIME DERIVATIVES NOT USED
```

```
          ISTD= 1
       RAD = 180. /PI
            IL= 8888
      NDIMC= 60
      CALL SFTUPS                                                  MAIN    4
       IF(ISTD .EQ. 1) GO TO  40
      DO 100 J = 1,300
      SCALS(J) =0.
      DO 100 I = 1,100
100   USAV (J,I) =0
 40    :  CONTINUE
C
         CALL RFADIN ( IL,& 60)
C                                                                  MAIN   65
C  NOTE - OFFSETS ARE PUT IN AS LISTED IN  THEORY OF WING SECTIONS, I.EMAIN   66
C        AS A FRACTION OF TOTAL CHORD, X1 BEING MEASURED FROM THE  MAIN   67
C        LEADING EDGE.  BE SURE NF IS AN EVEN NUMBER.              MAIN   68
C                                                                  MAIN   69
         TIME=0.
      NTIME=0
        NWAKE= 999
         ISEP=0
           ISEPT =0
          IWASH =2
            UINF  =1.
         L=0
      INDV=INDV+1                                                  MAIN   59
      WRITE(MOUT,6)                                                MAIN   72
      PITCH = ALPH1
      IF(INDV + MOTR .LE. 2) PITCH = PITCH - ALPH2
      IF(INDV .EQ. 2)
     X  AMPLU = 1.33333* XMUAVB * (1.-ROVB**3) / (1. - ROVB**4)
          IF( INDV.EQ. 2) FREQU= BDBR/RRDBR
      IF(INDV .GE. 2) GO TO 343
      WRITE(MOUT,25) NVOR,SVOR,HVOR,BARG,X1VOR,EMI,TORF,SSPA       MAIN   75
      RY=RY1                                                       MAIN   64
      HVOR=HVOR**2                                                 MAIN   76
      BARG=BARG/6.2832                                             MAIN   77
 343  CALL SECT(XU,YU,XL,YL,NOFF,NF,RDBB,TMDBB,CMDBB,THICK,CAMBR)  MAIN   78
      DO 7875 N=1,NF                                               MAIN   79
      CAMBR(N)=CAMBR(N)*CMDBB                                      MAIN   80
 7875 THICK(N)=THICK(N)*TMDBB                                      MAIN   81
      WRITE(MOUT,4)                                                MAIN   82
      WRITE(MOUT,7) AMPLU,FREQU,ALPH1,ALPH2,HEAVE,AROT,FREQF,RDBB,REB MAIN   83
      WRITE(MOUT,8)                                                MAIN   84
      WRITE(MOUT,9) (N,CAMBR(N),THICK(N),N=1,NF)                   MAIN   85
      MX=NSBL+NZ-1                                                 MAIN   86
      CALL SCAL(SBL,NSBL,FRZ,ARR,RDBB)                             MAIN   87
      CALL CORDX(NSBL,NZ,RDBB,SBL,X,XC)                            MAIN   88
      DO 2420 M=1,MX                                               MAIN   89
      IF(XC(M)-1.) 2420,2419,2419                                  MAIN   90
 2419 MEND=M-1                                                     MAIN   91
      GO TO 2421                                                   MAIN   92
 2420 CONTINUE                                                     MAIN   93
 2421 MX=MEND                                                      MAIN   94
```

```
      MXM1=MX-1
      UE(MX+1,1)=1.
      EPSLE=2.*(X(NZ)-X(NZ-1))
      EPSTE=X(MX)-X(MX-1)
      ALTC=8.36E4/SQRT(REB)
            IF( ISTD.EQ. 1) GO TO 50
      DO 2422 M=1,MX
      SCALE(M,1)=0.
      SCALE(M,2)=0.
      DO 2422 N=1,NY
      U(M,N,1)=0.
 2422 U(M,N,2)=0.
 50           CONTINUE
      NSIGA=NSIG
      NSIGB=NSIG
      NSIG1=NSIG+1
      MOTR=MOTR+1
      NOTBL=NOTBL+1
      XMAX=1.-ELSIG
      CONA=.375*PI/DXI
      ANGS=PI/FLOAT(NSIG)
      CALL SETSX(NSIG1,1.1,2.,XSIG,ANGS)
      XSEP=1.1
      DO 2430 N=1,NSIG1
      XSIGB(N)=XSIG(N)
 2430 XSIGA(N)=XSIG(N)
      DO 2431 N=1,NSIG
      DO 2431 NU=1,3
 2431 BCAP(N,NU)=0.
      PINT=2./FLOAT(NCORD)
      NCP1=NCORD+1
      THXI=1.5/DXI
      NGP1=NGAM+1
      NWM1=NWAKE-1
      COUNT=0.
      DO 8456 N=1,NWAKE
      GAMAW(N)=0.
      XIW(N)=1.+COUNT
 8456 COUNT=COUNT+DXI
      ANGLE=PI/FLOAT(NGAM)
      COUNT=0.
      DO 1002 M=1,NGP1
      PHIM=COUNT*ANGLE
      XGAM(M)=COS(PHIM)
      DOUNT=2.
      DO 1001 N=2,NGAM
      AS(M,N)=COS(DOUNT*PHIM)
 1001 DOUNT=DOUNT+1.
 1002 COUNT=COUNT+1.
      CALL WASH(XGAM,NGAM,TIME,ALPH1,ALPH2,HEAVE,AROT,FREQF,PHIH,UINF,CA
     1MBR,NF,VZIP,1,1)
      DO 8458 M=1,NGP1
      CMAT(M,1)=1.
      TEMP=2.*VZIP(M)
      RMAT(M)=TEMP
      CMAT(M,2)=XGAM(M)
      DO 8457 N=3,NGP1
 8457 CMAT(M,N)=AS(M,N-1)
 8458 CCNTINUE
      CALL ALSOL(NGP1,CMAT,RMAT)
      DO 8459 N=1,NGP1
      ACAP(N,1)=RMAT(N)
      ACAP(N,3)=RMAT(N)
 8459 ACAP(N,2)=ACAP(N,1)
      DO 2784 M=1,MX
      SIGN=1.
      IF(M-NZ) 2774,2775,2775
 2774 SIGN=-SIGN
 2775 CALL QECAL(ISEP,NGAM,NSIG,NF,XSIG,ACAP,BCAP,THICK,RCBB,GAMAW(1),UI
     1NF,XC(M),UF(M,1),SIGN)
 2784 UF(M,2)=UE(M,1)
      DO 1004 M=2,NGAM
 1004 BLAM(M)=(1.125*XGAM(M)+.1875*(1.+XGAM(M))*(1.-3.*XGAM(M))*ALOG((1.
     1+XGAM(M))/(1.-XGAM(M))))/DXI
      BLAM(NGP1)=-1.125/DXI
      CALL CLCM(NCOI,ISEP,NGAM,XSIG,NSIG,XSIGA,NSIGA,XSIGB,NSIGB,ACAP,BC
     1AP,THICK,RDBB,GAMAW,UINF,UDOT,DXI,AROT,CMPA)
           IF ( INDV .EQ. 2)
     1CALL SUPPL
C
C  INDEXING IN TIME IS CARRIED OUT AT THIS POINT.
C
 9999 CCNTINUE
          CALL ACUCPU( IACU )
         IF( IACU .LT.  35000  ) GO TO   99
C
C  NOTE - FOR READ-IN CF FCIL MOTIONS, MAKE ALPH1 = ALPHA,
C          ALPH2 = ALPHA-DOT, AND HEAVE = H-DOT.
C
      IF(MCTR .EQ. 2)
     XREAD(IN,2,END=8989) ALPH1,ALPH2,HEAVE
 158  NITS=1
      TIME=TIME+DXI
      NTIME=NTIME+1
      NWAKE=NTIME+2
      IF(NWAKE-998) 202,201,201
 201  NWAKE=998
 202  IF(MAXT-NTIME) 8989,8800,8800
 8800 SAVEU=UINF
           L= L+1
          P(L,1) =  BCBR / RRDBR * TIME   ●  RAD
         PSI360=  AMOD(  P(L,1) ,   360.)
      UINF=1.+AMPLU*SIN(FREQU*TIME)
      IF(INDV .EQ. 2)
     XCALL SUPP1(UINF)
      PITCH = ALPH1
      IF(INDV + MOTR .LE. 2) PITCH = PITCH - ALPH2*COS(FREQF*TIME)
      UDOT=FREQU*AMPLU*COS(FREQU*TIME)
      STEPX=.5*DXI*(UINF+SAVEU)
      DO 1003 J=2,NWAKE
      JC=NWAKE-J+2                                                      MAIN 194
      GAMAW(JC)=GAMAW(JC-1)                                             MAIN 195
 1003 XIW(JC)=XIW(JC-1)+STEPX                                           MAIN 196
      IF(ISEP) 2009,2009,2007                                           MAIN 197
 2007 DO 2008 N=1,NSIG                                                  MAIN 198
      BCAP(N,3)=BCAP(N,2)                                               MAIN 199
 2008 BCAP(N,2)=BCAP(N,1)                                               MAIN 200
      DO 4433 N=1,NSIG1                                                 MAIN 201
      XSIGB(N)=XSIGA(N)                                                 MAIN 202
 4433 XSIGA(N)=XSIG(N)                                                  MAIN 203
      GO TO 2010                                                        MAIN 204
 2009 DEADL=0.                                                          MAIN 205
      ELDOT=UINF                                                        MAIN 206
 2010 DO 1014 M=1,MX                                                    MAIN 207
      UE(M,3)=UE(M,2)                                                   MAIN 208
 1014 UE(M,2)=UE(M,1)                                                   MAIN 209
      DEAD1=DEADL                                                       MAIN 210
      ELD1=ELDOT                                                        MAIN 211
      ALAM(1)=(1.125+.75*ALOG(STEPX*.5))/DXI                            MAIN 212
      DO 1005 M=2,NGP1                                                  MAIN 213
 1005 ALAM(M)=BLAM(M)+.75*(1.+(1.-XGAM(M))/STEPX)*ALOG((1.+STEPX-XGAM(M)MAIN 214
     1)/(1.-XGAM(M)))/DXI                                               MAIN 215
      DO 2006 M=1,NGP1                                                  MAIN 216
      ACAP(M,3)=ACAP(M,2)                                               MAIN 217
 2006 ACAP(M,2)=ACAP(M,1)                                               MAIN 218
      AFACT=8.*(ACAP(1,2)+.5*ACAP(2,2))-2.*(ACAP(1,3)+.5*ACAP(2,3))     MAIN 219
      ALPHS=VZIP(1)                                                     MAIN 220
      CALL WASH(XGAM,NGAM,TIME,ALPH1,ALPH2,HEAVE,AROT,FREQF,PHIH,UINF,CAMAIN 221
     1MBR,NF,VZIP,MOTR,INDV)                                            MAIN 222
      DO 1006 M=1,NGP1                                                  MAIN 225
      ASZ(M)=1.+2.*ALAM(M)                                              MAIN 226
      AS(M,1)=XGAM(M)+ALAM(M)                                           MAIN 227
      SUM=0.                                                            MAIN 228
      DO 4343 J=2,NWM1                                                  MAIN 229
 4343 SUM=SUM+(GAMAW(J)+(GAMAW(J+1)-GAMAW(J))*(XGAM(M)-XIW(J))/(XIW(J+1)MAIN 230
     1-XIW(J)))*ALOG((XIW(J+1)-XGAM(M))/(XIW(J)-XGAM(M)))               MAIN 231
      ELX=1.-XGAM(M)                                                    MAIN 232
      IF(M-1) 1006,2130,1006                                            MAIN 233
 2130 ELX=1.                                                            MAIN 234
 1006 AR(M)=2.*VZIP(M)+ALAM(M)*AFACT/3.+(SUM-GAMAW(2)*(1.-XGAM(M))*ALOG(MAIN 235
     1(1.+STEPX-XGAM(M))/ELX)/STEPX)/PI                                 MAIN 236
C                                                                       MAIN 237
C  THE FOLLOWING CALCULATIONS, THROUGH STATEMENT 4444, ARE PERFORMED    MAIN 238
C   ONLY IF THE AIRFOIL IS STALLED.  THE AIRFOIL IS DESIGNATED TO BE    MAIN 239
C   STALLED IF INTEGER ISEP IS NONZERO.                                 MAIN 240
C                                                                       MAIN 241
      IF(ISEP) 3247,4444,3247                                           MAIN 242
 3247 GO TO (3344,3345),IWASH                                           MAIN 243
 3344 XSEP=XSEP+DXI                                                     MAIN 244
      IF(XSEP-XMAX) 3248,3347,3347                                      MAIN 245
 3347 IWASH=2                                                           MAIN 246
      ISEP=0                                                            MAIN 247
      XSEP=1.1                                                          MAIN 248
      DO 3015 K=1,3                                                     MAIN 249
      DO 3015 N=1,NSIG                                                  MAIN 250
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3015 BCAP(N,K)=0.                                                      MAIN 251
     GO TO 4444                                                        MAIN 252
3345 IF(INDT) 3348,3348,3248                                           MAIN 253
3348 IF(NITS-1) 3248,3349,3248                                         MAIN 254
3349 IF(INDV.EQ.2) GO TO 6349                                          MAIN 255
     IF(VZIP(1)-ALPHS) 6349,6348,6348                                  MAIN 256
6348 NITS=2                                                            MAIN 257
     GO TO 3248                                                        MAIN 258
6349 CALL UNPOP(NGAM,AR,ALAM,AFACT,RMAT,CMAT,XGAM,AS,ACAP,MX,NZ,NF,XSIGMAIN 259
    1,BCAP,THICK,RDBB,UINF,XC,UE)                                      MAIN 260
     GO TO 2785                                                        MAIN 261
3248 XATT=XSEP+DEAD1+.5*(ELD1+ELDOT)*DXI                               MAIN 262
     DEADL=XATT-XSEP                                                   MAIN 263
     DIFF=1.-XATT                                                      MAIN 264
         XTEST = XSEP + 3. * EPSLE
     CALL SETSX(NSIG1,XSEP,XATT,XSIG,ANGS)                             MAIN 265
     DO 4434 N=1,NSIG                                                  MAIN 266
4434 XBSIG(N)=.5*(XSIG(N)+XSIG(N+1))                                   MAIN 267
     DO 3086 M=1,NGP1                                                  MAIN 268
     DO 3086 N=1,NSIG                                                  MAIN 269
3086 BS(M,N)=0.                                                        MAIN 270
     DO 3087 M=1,NGP1                                                  MAIN 271
     IF(XGAM(M)-XSEP) 3088,3088,3089                                   MAIN 272
3C89 IF(XATT-XGAM(M)) 3187,3087,3091                                   MAIN 273
3C91 DO 3092 I=1,NSIG1                                                 MAIN 274
     IF(XGAM(M)-XSIG(I)) 3093,3092,3092                                MAIN 275
3093 MARK=I                                                            MAIN 276
     GO TO 3094                                                        MAIN 277
3C92 CCNTINUE                                                          MAIN 278
3C94 WIDES=XSIG(MARK)-XSIG(MARK-1)                                     MAIN 279
     BS(M,MARK-1)=(XSIG(MARK)-XGAM(M))/WIDES                           MAIN 280
     BS(M,MARK)=(XGAM(M)-XSIG(MARK-1))/WIDES                           MAIN 281
     BS(M,1)=SQRT((XGAM(M)-XSEP)/(XATT-XGAM(M)))                       MAIN 282
3088 IF(DIFF-1.E-6) 3087,3098,3098                                     MAIN 283
3C98 BS(M,1)=BS(M,1)+DIFF**(-1.5)*SQRT(DEADL)*(2.*DIFF+(SQRT((1.-XGAM(MMAIN 284
    1))/(XATT-XGAM(M)))-1.)*(4.*XGAM(M)-1.-3.*XATT))                   MAIN 285
     GO TO 3087                                                        MAIN 286
3187 BS(M,1)=DIFF**(-1.5)*SQRT(DEADL)*(3.+   XATT-4.*XGAM(M))          MAIN 287
3087 CONTINUE                                                          MAIN 288
C                                                                      MAIN 289
C    SET-UP OF THE SECOND SET OF EQUATIONS STARTS HERE.                MAIN 290
C                                                                      MAIN 291
     DO 4350 K=1,NSIG                                                  MAIN 292
     IF(XBSIG(K)-1.) 4348,4349,4349                                    MAIN 293
4348 CCSK=XBSIG(K)                                                     MAIN 294
     SINK=SQRT(1.-COSK*COSK)                                           MAIN 295
     THETK=ARCT(COSK)                                                  MAIN 296
     TANT=SIN(.5*THETK)/COS(.5*THETK)                                  MAIN 297
     ASHZ(K)=TANT+CONA*(1.+COSK)*(1.-3.*COSK)/UINF+THXI*(PI-THETK+SINK+MAIN 298
    1CONA*(1.+COSK)*SINK**2)/UINF                                      MAIN 299
     ASH(K,1)=.5*(ASHZ(K)-TANT)+SINK                                   MAIN 300
     COUNT=1.                                                          MAIN 301
     DO 4355 N=2,NGAM                                                  MAIN 302
     COUNT=COUNT+1.                                                    MAIN 303
4355 ASH(K,N)=SIN(COUNT*THETK)+.75*(SIN((COUNT+1.)*THETK)/(COUNT+1.)-SIMAIN 304
     1N((COUNT-1.)*THETK)/(COUNT-1.))/(DXI*UINF)
      GO TO 4350
 4349 ASHZ(K)=0.
      DO 4359 N=1,NGAM
 4359 ASH(K,N)=0.
 4350 CONTINUE
      IF(DIFF-1.E-6) 5005,5006,5006
 5005 PREC=0.
      GO TO 5007
 5006 CALL ATTPR(PREC,XSIG,NSIG,ASZ,AS,AR,CMAT,RMAT,NGAM,NF,ACAP,THICK,R
     1DBB,GAMAW,UINF,UDOT,DXI,BCAP)
 5007 CALL MIXER(FPRES,PREC,UINF,UDOT,THICK,NF,XBSIG,NSIG,INDT,DEL1,THET
     11,REB,USEP,X4,CP1)
      CPCT=CP1
      DO 4800 K=1,NSIG
      CORD=XBSIG(K)
      BSH(K,1)=-1.+THXI*BINT(XSEP,XATT,CORD)/UINF
      DO 4808 N=2,NSIG
 4808 BSH(K,N)=FB(XSIG(N-1),XSIG(N),XSIG(N+1),CORD)+THXI*GB(XSIG(N-1),XS
     1IG(N),XSIG(N+1),CORD)/UINF
      CALL ESIGI(2,NSIGA,XSIGA,BCAP,CORD,VAL1)
      CALL ESIGI(3,NSIGB,XSIGB,BCAP,CORD,VAL2)
      ARH(K)=FPRES(K)+(2.*VAL1-.5*VAL2)/(DXI*UINF)
      IF(CORD-1.) 5008,4800,4800
 5008 CALL EGAMI(2,NGAM,ACAP,BCAP(1,2),XSIGA(1),XSIGA(NSIGA+1),GAMAW(2),
     1CORD,VAL1)
      CALL EGAMI(3,NGAM,ACAP,BCAP(1,3),XSIGB(1),XSIGB(NSIGB+1),GAMAW(3),
     1CORD,VAL2)
      ARH(K)=ARH(K)+(2.*VAL1-.5*VAL2)/(DXI*UINF)+.0625*AFACT*PI*(1.+CORD
     1)*(1.-3.*CORD+THXI*(1.-CORD*CORD))/(DXI*UINF)
 4800 CONTINUE
 4444 CONTINUE
C
C     CALCULATIONS FROM THIS POINT ON COMBINE THE
C     CASES OF STALLED AND UNSTALLED AIRFOILS.
C
      DO 6500 M=1,NGP1
      RMAT(M)=AR(M)
      CMAT(M,1)=ASZ(M)
      DO 6485 N=1,NGAM
 6485 CMAT(M,N+1)=AS(M,N)
      IF(ISEP) 6486,6500,6486
 6486 DO 6499 N=1,NSIG
      NGG=N+NGP1
 6499 CMAT(M,NGG)=BS(M,N)
 6500 CONTINUE
      IF(ISEP) 6502,6501,6502
 6501 NTOT=NGP1
      GO TO 6751
 6502 DO 6750 K=1,NSIG
      KK=K+NGP1
      RMAT(KK)=ARH(K)
      CMAT(KK,1)=ASHZ(K)
      DO 6748 N=1,NGAM
 6748 CMAT(KK,N+1)=ASH(K,N)
```

```
      DO 6750 N=1,NSIG
      NGG=N+NGP1
 6750 CMAT(KK,NGG)=BSH(K,N)
      NTOT=NSIG+NGP1
 6751 CALL ALSOL(NTOT,CMAT,RMAT)
      DO 6800 N=1,NGP1
 68CC ACAP(N,1)=RMAT(N)
      IF(ISEP) 6805,6820,6805
 6EC5 DO 6810 N=1,NSIG
      NGG=N+NGP1
 6E10 BCAP(N,1)=RMAT(NGG)
 6820 CONTINUE
      GAMAW(1)=GAM1(ACAP,DXI,PI)
        IF( PSI360  .GE. PSILOW .AND. PSI360  .LE. PSIUP) GO TO 1736
      DO 1785 M=1,MX
      SIGN=1.
      IF(M-NZ) 1780,1785,1785
 1780 SIGN=-SIGN
 1785 CALL QECAL(ISEP,NGAM,NSIG,NF,XSIG,ACAP,BCAP,THICK,RDBB,GAMAW(1),UI
     1NF,XC(M),UE(M,1),SIGN)
 27E5 DO 8886 I=1,2
      US2=UE(1,1)
      DO 8886 M=1,MXM1
      US1=UE(M,1)
      UE(M,1)=(US1+US2+UE(M+1,1))/3.
 E886 US2=US1
      GO TO (8351,8353),IWASH
 8351 DO 8352 M=1,MX
 8352 SCALS(M)=0.
      GO TO 1786
 8353 CALL YSET(RY1,Y(2),NY,Y)
      RY=RY1
      DO 8354 M=1,MX
 8354 SCALS(M)=0.
      IF(INDV.EQ.2) GO TO 8370
      IF(ISEP.EQ.0.AND.VZIP(1).LT.ALPHS) GO TO 1786
 8370 CALL STAG(MX,NY,MSTOP,MST,DXI,RY,DRY,X,Y,UE,UC,V,USAV,SCALS,ISEP)
      LAMQ=1
      XSEPS=XSEP
      DXX=DXI
      IF(ISEP.EQ.1.AND.ISEPT.EQ.0.AND.NITS.EQ.1) DXX=1.E30
 8367 CALL BLC(X,Y,MST,MEND,NY,RY,DRY,DXX,REB,UPRIM,FLAM,XFLAM,TEST,U,SC
     1ALE,UE,UC,V,XSEP,USEP,DISP,THETA,LOWER,LAMQ,MSEP,XC,USAV,SCALS,NIT
     1S,NTIME, NOTBL , XTEST, NZ, NOUT)
      IF(XSEP-XMAX) 7736,7735,7735
 7735 IF(ISEP) 1786,1786,7736
 7736 DEL1=DISP
      THET1=THETA
      INDT=1-LAMQ
      IF(INDT.EQ.1.AND.NOTBL.EQ.2) GO TO 1786
      WRITE(MOUT,23) XSIG(1),CPCT,XSEP
      IF(INDT) 8462,8462,8463
 8462 IF(ISEP) 8562,8562,8563
 8563 IF(NITS-1) 8562,8562,8562
 8662 IF(ISEPT) 7742,7742,8562
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```
8562 CALL BUBB(DEL1,THET1,RFB,XSEP,USEP,XC5,DCP,DEL5,X,XC,MX,NZ,X5,U5,U
    1F,ALTC,RENEL,USTOP)
     USEP=USEP+.002046*USEP**3
     PDIFF=(USEP-U5)*(USEP+U5)
     WRITF(MOUT,22) PDIFF,DCP
     IF(DCP-PDIFF) 8263,8366,8366
8263 ISEPT=0
     GO TO 8463
8366 IF(ISEP) 8368,8368,8369
8369 IF(ISEPT) 8467,8467,8368
8467 IWASH=1
     NITS=2
     GO TO 3344
8368 GO TO (8168,1786),NOTBL
8168 CALL REATT(UC,V,X,Y,MX,NY,RY,DRY,UE,X5,DEL5,MST,REB)
     LAMQ=0
     GO TO 8367
8463 IF(ISEP) 7741,7741,7742
7741 ISEP=1
     NITS=NITS+1
     IF(INDT) 7743,7743,7643
7643 ISEPT=1
     DXSEP=1.-XSEP
     XSEP=.6*XSEP+.4
     CALL CPC(ISEP,NGAM,NF,XSIG,NSIG,XSIGA,NSIGA,XSIGB,NSIGB,ACAP,BCAP,
    1THICK,RDBB,GAMAW,UINF,UDOT,1.,XSEP,DXI,CP1)
     GO TO 3248
7742 CALL ELDER(BCAP,XSIG,NSIG,UINF,ELDOT,SIGSUM,YMX)
     IF(ISEP.EQ.1.AND.ISEPT.EQ.0.AND.NITS.EQ.1) GO TO 9210
     IF(XSEP+.5) 7841,7842,7842
7841 EPS=EPSLE
     GO TO 7843
7842 EPS=EPSTE
7843 DXSEP=ABS(XSEP-XSEPS)
     IF(DXSEP-EPS) 7834,7834,9210
7834 IF(XSEP-XMAX) 1786,1786,7835
7835 ISEP=0
     ISEPT=0
     DO 7836 K=1,3
     DO 7836 N=1,NSIG
7836 BCAP(N,K)=0.
     GO TO 1786
9210 NITS=NITS+1
     IF(NITS.EQ.2.AND.INDT.EQ.0) XSEPS=XSEP
     IF(NITS-4) 9211,9211,1786
9211 IF(XSEP-XSEPS) 9305,9305,9306
9305 XSEP=.6*XSEPS+.4*XSEP
     GO TO 9307
9306 XSEP=.6*XSEP+.4*XSEPS
9307 IF(XSEP-XMAX) 9212,9212,7835
9212 CALL CPC(ISEP,NGAM,NF,XSIG,NSIG,XSIGA,NSIGA,XSIGB,NSIGB,ACAP,BCAP,
    1THICK,RDBB,GAMAW,UINF,UDOT,1.,XSEP,DXI,CP1)
       IF( NOTBL .EQ. 2 .AND. XSEP .GT. 0.) XSEP=-.98
     GO TO 3248
7743 IF(NITS-1) 7737,7737,3248
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 7737 NITS=NITS+1                                                          MAIN 470
      ELDOT=ELD1                                                           MAIN 471
      GO TO 3248                                                           MAIN 472
 1786 WRITE(MOUT,20) NTIME                                                 MAIN 473
      WRITE(MOUT,26) XIVOR                                                 MAIN 477
      PITC  = PITCH * 180. / PI
 209  WRITE(MOUT,10) TIME,UINF,XSEP,XATT,PITC                              MAIN 478
            ALDEG= ALPH1/DEGRES                                            SUPPL349
      WRITE(6, 9001)  Z,ALDEG,ALPH1 ,  ALPH2, HEAVE                        SUPPL350
        IF( PSI360  .GE. PSILOW .AND. PSI360  .LE. PSIUP) GO TO 101
            IF( NOUT .EQ. 0)
     1WRITE(MOUT,11)                                                       MAIN 479
            IF( NOUT .EQ. 0)
     1WRITE(MOUT,12) (N,XGAM(N),VZIP(N),AR(N),ACAP(N, 1),XIW(N ),GAMAW(N),MAIN 480
     2N=1,NGP1)                                                            MAIN 481
      IF(ISEP) 7432,7433,7432                                              MAIN 482
 7432       IF( NOUT .EQ. 0)
     1WRITE(MOUT,13)                                                       MAIN 483
            IF( NOUT .EQ. 0)
     1WRITE(MOUT,17) (N,XBSIG(N),FPRES(N),ARH(N),BCAP(N, 1),N=1,NSIG)      MAIN 484
      WRITE(MOUT,14) ELDOT                                                 MAIN 485
      WRITE(MOUT,18) XSIG(1),CPOT,X4,CPOT,XATT,PREC                        MAIN 486
 7433 WRITE(MOUT,15)                                                       MAIN 487
      XPC=-1.                                                              MAIN 488
      DO 7102 N=1,NCP1                                                     MAIN 489
      CALL QECAL(ISEP,NGAM,NSIG,NF,XSIG,ACAP,BCAP,THICK,RDBB,GAMAW(1),UIMAIN 490
     1NF,XPC,QEL,-1.)                                                      MAIN 491
      CALL QECAL(ISEP,NGAM,NSIG,NF,XSIG,ACAP,BCAP,THICK,RDBB,GAMAW(1),UIMAIN 492
     1NF,XPC,QEU,1.)                                                       MAIN 493
      CALL CPC(ISEP,NGAM,NF,XSIG,NSIG,XSIGA,NSIGA,XSIGB,NSIGB,ACAP,BCAP,MAIN 494
     1THICK,RDBB,GAMAW,UINF,JDOT,1.0,XPC,DXI,CPU)                          MAIN 495
      CALL CPC(ISEP,NGAM,NF,XSIG,NSIG,XSIGA,NSIGA,XSIGB,NSIGB,ACAP,BCAP,MAIN 496
     1THICK,RDBB,GAMAW,UINF,UDOT,-1.,XPC,DXI,CPL)                          MAIN 497
      IF(N-1) 7546,7545,7546                                               MAIN 498
 7545 CPL=CPU                                                              MAIN 499
 7546 DLIFT=CPL-CPU                                                        MAIN 500
      WRITE(MOUT,16) XPC,QEL,CPL,QEU,CPU,DLIFT                             MAIN 501
 7102 XPC=XPC+PINT                                                         MAIN 502
101         CONTINUE
      CMPAS=CMPA                                                           MAIN 503
      CALL CLCM(NCOI,ISEP,NGAM,XSIG,NSIG,XSIGA,NSIGA,XSIGB,NSIGB,ACAP,BCMAIN 504
     1AP,THICK,RDBB,GAMAW,UINF,UDOT,DXI,AROT,CMPA)                         MAIN 505
            P(L,2) =  PITC
            P(L,3) =  Z(3)
            P(L,4) =  Z(1)
            P(L,5) =  Z(2)
            P(L,6) =  CLVB
            P(L,7) =  CMPA
            IF( L .LT.  200 )  GO TO   98
            CALL   PLOTSB( PLOTOP  ,  P  ,  L )
            L= 0
  98    CONTINUE
        IF(ISTD .EQ. 1) GO TO   9999
      DO 7950 M=1,MX                                                       MAIN 506
      SCALE(M,2)=SCALE(M,1)                                                MAIN 507
      SCALE(M,1)=SCALS(M)                                               MAIN 508
      DC 7950 N=1,NY                                                    MAIN 509
      U(M,N,2)=U(M,N,1)                                                 MAIN 510
 7950 U(M,N,1)=USAV(M,N)                                                MAIN 511
      GO TO 9999                                                        MAIN 512
 8989 CONTINUE                                                          MAIN 513
  99       CONTINUE
             CALL    PLOTSB( PLOTOP   ,   P   ,   L  )
           CALL ACUCPU( IACU )
          IF( IACU .LT.  35000  ) GO TO  60
           GO TO 40
 60          CONTINUE
              IF( PLOTOP.EQ. 0.)   CALL EXIT
         CALL PLTND
         CALL  EXIT
            RETURN
C
C
C
C
 1    FORMAT(13I5)                                                      MAIN  23
 2    FORMAT(3F10.4)                                                    MAIN  24
 3    FORMAT(2F10.4)                                                    MAIN  25
 4    FORMAT(1H1//)                                                     MAIN  26
 5    FORMAT(6F10.4)                                                    MAIN  27
 6    FORMAT(1H1,50X,34HANALYSIS OF UNSTEADY AIRFOIL STALL///)          MAIN  28
 7    FORMAT(8X,6HUBAR =E13.5/7X,7HUFREQ =E13.5//3X,11HALPHA ONE =E13.5/MAIN  29
     13X,11HALPHA TWO =E13.5/8X,6HHBAR =E13.5/11X,3HA =E13.5/8X,6HFREQ =MAIN  30
     1E13.5//8X,6HRO/B =E13.5//9X,5HREB =E13.5///)                      MAIN  31
 8    FORMAT(29X,1HN,25X,4HC(N),26X,4HT(N)/)                            MAIN  32
 9    FORMAT(I30,2E30.5)                                                MAIN  33
 10   FORMAT(5X,3HT =E13.5/5X,3HU =E13.5/4X,4HXS =E13.5/4X,4HXO =E13.5/4MAIN  34
     1X,4HPA =E13.5////)                                                MAIN  35
 11   FORMAT(///4X,1HN,11X,1HX,14X,5HVZ(X),12X,5HRN(X),12X,4HA(N),21X,3HMAIN  36
     1XIW,14X,5HGAMMA/)                                                 MAIN  37
 12   FORMAT(I5,4E17.5,8X,2E17.5)                                       MAIN  38
 13   FORMAT(1H1,8X,1HN,20X,1HX,21X,5HFP(X),22X,5HRH(N),21X,4HB(N)/)    MAIN  39
 14   FORMAT(//54X,9H  L-DCT =E13.5///51X,27HPRESSURES IN SEPARATED FLOWMAIN  40
     1//55X,1HX,19X,2HCP/)                                              MAIN  41
 15   FORMAT(1H1,11X,1HX,16X,3HQEL,15X,3HCPL,15X,3HQEU,15X,3HCPU,13X,9HCMAIN  42
     1PL - CPU/)                                                        MAIN  43
 16   FORMAT(6E18.5)                                                    MAIN  44
 17   FORMAT(I10,4E25.5)                                                MAIN  45
 18   FORMAT(3(40X,2E20.5/))                                            MAIN  46
 19   FORMAT(I5,5F10.4)                                                 MAIN  47
 20   FORMAT(1H1,50X,12HTIME STEP NOI3//)                               MAIN  48
 22   FORMAT(///40X,26HINCREASE IN CP REQUIRED ISE13.5//40X,26HINCREASE MAIN  49
     1IN CP POSSIBLE ISE13.5)                                           MAIN  50
 23   FORMAT(///45X,23HPOTENTIAL FLOW     XS =E12.4/60X,8HCP(XS) =E12.4/MAIN  51
     1/45X,23HBOUNDARY LAYER     XS =E12.4)                             MAIN  52
 24   FORMAT(I5,4F10.4/5F10.4)                                          MAIN  53
 25   FORMAT(12X,4HNV =I2,3X,3HS =E12.4,3X,3HH =E12.4,3X,3HG =E12.4,3X,4MAIN  54
     1HX1 =E12.4//12X,4HMI =E12.4,3X,4HWT =E12.4,3X,4HPA =E12.4///)     MAIN  55
 26   FORMAT(4X,4HX1 =E13.5)                                            MAIN  56
 9001 FORMAT('0', T50,  'EQUIVALENT ROTOR BLADE RESPONSE'               SUPPL380
9001A  //   T 5,   'FLAP DISP =',        G14.5                                          SUPPL381
9001B   ,   T47,   'BENDING DISP =',  G14.5                                             SUPPL382
9001C   ,   T39,   'TORSIONAL DISP =', G14.5                                            SUPPL383
9001D   /   T38,   'SECTION PITCH ANGLE =', F9.3, ' DEGREES OR',                        SUPPL384
9001E                                        F9.4, ' RADIANS '                          SUPPL385
9001F   /   T21,   'SECTION PITCH RATE =',   G14.5                                      SUPPL386
9001G   ,   T71,   'SECTION PLUNGING RATE =',  G14.5     //)                            SUPPL387
     END                                                                                MAIN 515
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      SUBROUTINE SUPPL                                                  SUPPL   1
      IMPLICIT REAL*8 (A-H,O-Z)                                         SUPPL   2
      REAL*8 FR1S, FR2S, FR3S, ANSX, OMS                                SUPPL   3
C                                                                       SUPPL   4
      REAL*4              CLVB, CMVB,  CMPAVB
     1 , DUMMY, PLOTOP
      REAL   FTVB,  FPVB,  FPPRVB,  DIDRVB,  XMVB,  DELVB,  XMUVB,      SUPPL   5
     A     FOVB,  XMUAVB,  ATOVB,  ATCVB,  ATSVB,  ROVB,  RVB,  MVB,    SUPPL   6
     C     WDXI,   PSI, UINF                                            SUPPL   7
      REAL   ELSIG,  DXI,  REB,  RDBB,  FRZ,  ARR,  AMPLU,  FREQU,      SUPPL   8
     A   ALPH1,  ALPH2,  HEAVE,  AROT,  FREQF,  PHIH,        RY1,  DRY, SUPPL   9
     B   X,  TEST,  UPRIM,  XU,  YU,  XL,  YL,  ER1,  ER2,  ER3,  BDBR, SUPPL  10
     C     RRDBR                                                        SUPPL  11
      REAL   SUM(8), YCLD(8), YNEW(8), DEL(3,3), CMPA(3), CL(3), G(3),  SUPPL  12
     A   Z    , ZPR(3), SMALLG(3), Y(3,3), YPR(3,3),GCAP(3,3)           SUPPL  13
      COMMON /BL1/        NTIME, NDIMC
      COMMON /CLCMBL/   CLVB, CMVB,  CMPAVB                             MAIN
         COMMON/ ZZZ/ Z(3)
      COMMON /INPTVB/   FTVB(64),  FPVB(64),  FPPRVB(64),  DIDRVB(64),  SUPPL  15
     A        XMVB(64),   DELVB,      XMUVB,      FOVB,     XMUAVB,     SUPPL  16
     B        ATOVB,      ATCVB,      ATSVB,      ROVB,       RVB(64),  SUPPL  17
     C        MVB(64),    NVB                                           SUPPL  18
      CCMMON /INPUTS/   NSBL,      NZ,        NOFF,      NGAM,     NSIG, SUPPL  19
     A          NCOI,     NCORD,     LOWER,     MSTOP,     MAXT,     MOTR, SUPPL  20
     B          NOTBL,    INDV,      ELSIG,     DXI,       REB,      RDBB, SUPPL  21
     C          FRZ,      ARR,       AMPLU,     FREQU,     ALPH1,   ALPH2, SUPPL  22
     D          HEAVE,    AROT,      FREQF,     PHIH,      NY,        RY1, SUPPL  23
     E          DRY,      X(100),    TEST,      UPRIM,     XU(30),  YU(30), SUPPL  24
     F          XL(30),   YL(30),    ER1,       ER2,       ER3,      BDBR, SUPPL  25
     G          RRDBR                                                   SUPPL  26
     H , DUMMY(10),PLOTOP
      DIMENSION DELTA(3,3)                                              SUPPL  27
      DIMENSION ALPHA(3,3),BETA(3,3),GAMMA(3,3),OMS(3),OMEGA(3),CHK(3)  SUPPL  28
      DIMENSION AA(10),AB(10),ANB(20),ANT(20),AAX(10),ANSX(20),SORT(3)  SUPPL  29
     1  , TOT(2)
      CF4(X)=F4-B4+(B4*C6-C4)*X*X                                       SUPPL  30
      Z1(X)=HB*(CF4(X)/GB)**2+(CF4(X)*FR1S+(1.-C6*X*X)*B2-F2)*X*X       SUPPL  31
      Z2(X)=(FZ/FR1S+FR1S*CF4(X)-F2+(1.-C6*X*X)*(B2-BZ/FR1S))*X*X       SUPPL  32
      S1(X)=(2.*HB*CF4(X)/GB**2+(FR1S-FR2S)*X*X)*GA                     SUPPL  33
      S2(X)=(FR1S-FR2S)*GA*X*X                                          SUPPL  34
      FUN(X)=(R1*Z2(X)-R2*Z1(X))**2+(R1*S2(X)-R2*S1(X))*(Z2(X)*S1(X)-Z1(SUPPL  35
     1X)*S2(X))                                                         SUPPL  36
      DATA BBS,REL,NPOL/1.E-7,1.E-6,3/                                  SUPPL  39
C                                                                       SUPPL  40
C  MASSES AND H'S ARE NCNDIMENSIONAL, WITH BLADE MASS AND RADIUS        SUPPL  41
C  AS REFERENCES.  NONROTATING NATURAL FREQUENCIES ARE                  SUPPL  42
C  DIMENSIONLESS, USING ROTOR SPEED AS REFERENCE.  DISTANCES XBAB, S1LB,SUPPL  43
C  AND S2LB ARE FRACTICNS OF SEMICHORD.  XBAR, S1L, AND S2L ARE         SUPPL  44
C  FRACTIONS OF ROTOR RADIUS.                                           SUPPL  45
C                                                                       SUPPL  46
      NDIMC=3
      DO  63 K = 1, 8                                                   SUPPL  47
      SUM(K) = 0.                                                       SUPPL  48
   63 YNEW(K) = 0.                                                      SUPPL  49
      DO 69  I = 1, NVB                                                 SUPPL  50
      DO 66 K = 1, 8                                                    SUPPL 51
66    YOLD(K) = YNEW(K)                                                 SUPPL 52
      CALL YVB(YNEW,I)                                                  SUPPL 53
      IF(I .LE. 1) GO TO 69                                             SUPPL 54
      DO 67 K = 1, 8                                                    SUPPL 55
67    SUM(K) = (YNEW(K) + YOLD(K)) * (RVB(I) - RVB(I-1)) / 2. + SUM(K)  SUPPL 56
69    CONTINUE                                                          SUPPL 57
      EM11 = SUM(1)                                                     SUPPL 59
      EM22 = SUM(2)                                                     SUPPL 60
      EM33 = SUM(3)                                                     SUPPL 61
      EM13 = SUM(4)                                                     SUPPL 62
      EM23 = SUM(5)                                                     SUPPL 63
      H11 = SUM(6)                                                      SUPPL 64
      H22 = SUM(7)                                                      SUPPL 65
      H33 = - EM33                                                      SUPPL 66
      H13 = -EM13                                                       SUPPL 67
      H23 = SUM(8)                                                      SUPPL 68
      BDBRR=BDBR/RRDBR                                                  SUPPL 69
      BDS=BDBRR**2                                                      SUPPL 70
      T11=H11*BDS                                                       SUPPL 71
      T22=H22*BDS                                                       SUPPL 72
      T33=H33*BDS                                                       SUPPL 73
      T13=H13*BDS                                                       SUPPL 74
      T23=H23*BDS                                                       SUPPL 75
      FR1S=BDS*ER1**2-T11/EM11                                          SUPPL 76
      FR2S=ER2**2*BDS-T22/EM22                                          SUPPL 77
      FR3S=ER3**2*BDS-T33/EM33                                          SUPPL 78
      FR1=DSQRT(FR1S)                                                   SUPPL 79
      FR2=DSQRT(FR2S)                                                   SUPPL 80
      FR3=DSQRT(FR3S)                                                   SUPPL 81
      RATM=EM11/EM22                                                    SUPPL 82
      ZETA=(1.+RATM)*(RATM*FR1S**2+FR2S**2)/(RATM*FR1S+FR2S)**2         SUPPL 83
      RM=ZETA-1.                                                        SUPPL 84
      SUMS=FR1S+FR2S                                                    SUPPL 85
      HIGHS=(SUMS+DSQRT(SUMS**2-4.*ZETA*FR1S*FR2S))/(2.*ZETA)           SUPPL 86
      SMALS=FR1S*FR2S/HIGHS                                             SUPPL 87
      DEN=FR2S-FR1S                                                     SUPPL 88
      A1=-(HIGHS-FR1S)/DEN                                              SUPPL 89
      A2=-1.-A1                                                         SUPPL 90
      B=-A1*A2*DEN/HIGHS                                                SUPPL 91
      SLAM1=EM11*BDBR**2/EM33                                           SUPPL 92
      SLAMZ=-A1*SLAM1                                                   SUPPL 93
      SLAM2=-SLAMZ/A2                                                   SUPPL 94
      SUM3=SUMS+FR3S                                                    SUPPL 95
      ADD2=FR1S*(FR2S+FR3S)+FR2S*FR3S                                   SUPPL 96
      ADDZ=FR1S*FR2S*FR3S                                               SUPPL 97
      BBAR=1.-(EM13**2/EM11+EM23**2/EM22)/EM33                          SUPPL 98
      B4=SUM3+(2.*EM23*T23/EM22+2.*EM13*T13/EM11-FR1S*EM23**2/EM22-FR2S*SUPPL 99
     1EM13**2/EM11)/EM33                                                SUPPL100
      B4=B4/BBAR                                                        SUPPL101
      B2=ADD2+(2.*FR2S*EM13*T13/EM11+2.*FR1S*EM23*T23/EM22-T13**2/EM11-TSUPPL102
     123**2/EM22)/EM33                                                  SUPPL103
      B2=B2/BBAR                                                        SUPPL104
      BZ=ADDZ-(FR2S*T13**2/EM11+FR1S*T23**2/EM22)/EM33                  SUPPL105
      BZ=BZ/BBAR                                                        SUPPL106
      C6=(EM11*A1**2+EM22*A2**2)/EM33                                   SUPPL107
      F4=SUM3                                                           SUPPL108
      C4=(FR2S*EM11*A1**2+FR1S*FM22*A2**2)/ FM33                        SUPPL109
      GA=2.*EM11*A1/EM33                                                SUPPL110
      GB=2.*EM22*A2/EM33                                                SUPPL111
      F2=ADD2                                                           SUPPL112
      HA=EM11/FM33                                                      SUPPL113
      HB=EM22/EM33                                                      SUPPL114
      FZ=ADDZ                                                           SUPPL115
      R1=-HA-HB*(GA/GB)**2                                              SUPPL116
      R2=HA*(FR2S/FR1S-1.)                                              SUPPL117
      ZLAM=F4-B4                                                        SUPPL118
      TWLAM=B4*C6-C4                                                    SUPPL119
      FZHAT=HB*(ZLAM/GB)**2                                             SUPPL120
      F2HAT=B2-F2+FR1S*ZLAM+2.*ZLAM*TWLAM*HB/GB**2                      SUPPL121
      F4HAT=-C6*B2+FR1S*TWLAM+HB*(TWLAM/GB)**2                          SUPPL122
      G2HAT=B2-F2+(FZ-BZ)/FR1S+FR1S*ZLAM                                SUPPL123
      G4HAT=-C6*(B2-BZ/FR1S)+FR1S*TWLAM                                 SUPPL124
      SIGZ=2.*HB*ZLAM*GA/GB**2                                          SUPPL125
      SIG2=GA*(FR1S-FR2S+2.*HB*TWLAM/GB**2)                             SUPPL126
      GAM2=GA*(FR1S-FR2S)                                               SUPPL127
      UZ=-R2*FZHAT                                                      SUPPL128
      U1=R1*G2HAT-R2*F2HAT                                              SUPPL129
      U2=R1*G4HAT-R2*F4HAT                                              SUPPL130
      U3=-R2*SIGZ                                                       SUPPL131
      U4=R1*GAM2-R2*SIG2                                                SUPPL132
      U5=SIGZ*G2HAT-GAM2*FZHAT                                          SUPPL133
      U6=SIGZ*G4HAT+SIG2*G2HAT-GAM2*F2HAT                               SUPPL134
      U7=SIG2*G4HAT-GAM2*F4HAT                                          SUPPL135
      AAX(1)=UZ**2                                                      SUPPL136
      AAX(2)=2.*UZ*U1+U3*U5                                             SUPPL137
      AAX(3)=U1**2+2.*UZ*U2+U3*U6+U4*U5                                 SUPPL138
      AAX(4)=2.*U1*U2+U3*U7+J4*U6                                       SUPPL139
      AAX(5)=U2**2+U4*U7                                                SUPPL140
      CALL POLLY(4,BBS,REL,ANSX,AAX)                                    SUPPL141
      XBAR=1.E25                                                        SUPPL142
      DO 86 I=1,4                                                       SUPPL143
      IP=2*I                                                            SUPPL144
      IM=IP-1                                                           SUPPL145
      IF(DABS(ANSX(IM)).GT.1.D-10) GO TO 86                             SUPPL146
      IF(ANSX(IP).LE.0.) GO TO 86                                       SUPPL147
      XBART=DSQRT(ANSX(IP))                                             SUPPL148
      IF(XBART.LT.XBAR) XBAR=XBART                                      SUPPL149
   86 CONTINUE                                                          SUPPL150
      IF(XBAR.LT..5E25) GO TO 88                                        SUPPL151
      WRITE(6,87)                                                       SUPPL152
   87 FORMAT(1H1,10X,'NC SOLUTICN FOR XBAR')                            SUPPL153
      STOP                                                              SUPPL154
   88 CONTINUE                                                          SUPPL155
   15 ALOW=(R1*Z2(XBAR)-R2*Z1(XBAR))/(R1*S2(XBAR)-R2*S1(XBAR))          SUPPL156
      ALOW=ALOW/XBAR                                                    SUPPL157
      BLOW=(CF4(XBAR)-GA*ALOW*XBAR)/(XBAR*GB)                           SUPPL158
      XI=-ALOW-BLOW                                                     SUPPL159
      ETA=(BLOW*A1-ALOW*A2)/(A1-A2)                                     SUPPL160
      S2L=ETA/(B*HIGHS)                                                 SUPPL161
      S1L=(XI-RM*HIGHS*S2L)*HIGHS/(FR1S*FR2S)                           SUPPL162
      WRITE(6,4) FR1,FR2,FR3,RM                                         SUPPL163
      WRITE(6,721) FR1,FR2,FR3,ALOW,BLOW                                SUPPL164
      WRITE(6,5) EM11,EM22,EM33,EM13,EM23                               SUPPL165
      WRITE(6,6) H11,H22,H33,H13,H23                                    SUPPL166
      C13=ALOW/BDBR                                                     SUPPL167
      C23=BLOW/BDBR                                                     SUPPL168
      XBAB=XBAR/BDBR                                                    SUPPL169
      S1LB=S1L/BDBR                                                     SUPPL170
      S2LB=S2L/BDBR                                                     SUPPL171
      WRITE(6,41) BDBR,RRDBR                                            SUPPL172
      WRITE(6,7) XBAR,XBAB,S1L,S1LB,S2L,S2LB,SMALS,HIGHS                SUPPL173
      AA(1)=B7                                                          SUPPL174
      AA(2)=B2                                                          SUPPL175
      AA(3)=B4                                                          SUPPL176
      AA(4)=1.                                                          SUPPL177
      CALL POLLY(NPOL,BBS,REL,ANB,AA)                                   SUPPL178
      SSX=SLAMZ*XBAB                                                    SUPPL179
      DIV=1.-SLAMZ*XBAB**2                                              SUPPL180
      BETA(3,1)=(SLAM1*C13+SSX*FR1S)/DIV                                SUPPL181
      BETA(3,2)=(SLAM2*C23+SSX*FR2S)/DIV                                SUPPL182
      BETA(3,3)=(FR3S+SSX*(C13+C23))/DIV                                SUPPL183
      AXB=A1*XBAB                                                       SUPPL184
      BETA(1,1)=FR1S-AXB*BETA(3,1)                                      SUPPL185
      BETA(1,2)=-AXB*BETA(3,2)                                          SUPPL186
      BETA(1,3)=C13-AXB*BETA(3,3)                                       SUPPL187
      AAXB=A2*XBAB                                                      SUPPL188
      BETA(2,1)=-AAXB*BETA(3,1)                                         SUPPL189
      BETA(2,2)=FR2S-AAXB*BETA(3,2)                                     SUPPL190
      BETA(2,3)=C23-AAXB*BETA(3,3)                                      SUPPL191
      AB(4)=1.                                                          SUPPL192
      AB(3)=BETA(1,1)+BETA(2,2)+BETA(3,3)                               SUPPL193
      AB(2)=BETA(1,1)*(BETA(2,2)+BETA(3,3))+BETA(2,2)*BETA(3,3)-BETA(3,2SUPPL194
     1)*BETA(2,3)-BETA(1,2)*BETA(2,1)-BETA(1,3)*BETA(3,1)               SUPPL195
      AB(1)=BETA(1,1)*(BETA(2,2)*BETA(3,3)-BETA(3,2)*BETA(2,3))-BETA(2,1SUPPL196
     1)*(BETA(1,2)*BETA(3,3)-BETA(3,2)*BETA(1,3))+BETA(3,1)*(BETA(1,2)*BSUPPL197
     1ETA(2,3)-BETA(1,3)*BETA(2,2))                                     SUPPL198
      CALL POLLY(NPOL,BBS,REL,ANT,AB)                                   SUPPL199
      WRITE(6,44)                                                       SUPPL200
      DO 45 I=1,4                                                       SUPPL201
      IM=(I-1)*2                                                        SUPPL202
45    WRITE(6,46) IM,AA(I),AB(I)                                        SUPPL203
      WRITE(6,47)                                                       SUPPL204
      DO 48 I=1,3                                                       SUPPL205
      ITT=2*I                                                           SUPPL206
      ITM=ITT-1                                                         SUPPL207
48    WRITE(6,49) ANB(ITT),ANB(ITM),ANT(ITT),ANT(ITM)                   SUPPL208
      DO 301 I=1,3                                                      SUPPL209
      II=2*I                                                            SUPPL210
301   OMS(I)=-ANT(II)                                                   SUPPL211
      MAXI=3                                                            SUPPL212
      DO 70 I=1,2                                                       SUPPL213
      IF(OMS(I).GT.OMS(MAXI)) MAXI=I                                    SUPPL214
70    CONTINUE                                                          SUPPL215
      GO TO (71,72,73),MAXI                                             SUPPL216
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71    I1=2                                                              SUPPL217
      I2=3                                                              SUPPL218
      GO TO 74                                                          SUPPL219
72    I1=1                                                              SUPPL220
      I2=3                                                              SUPPL221
      GO TO 74                                                          SUPPL222
73    I1=1                                                              SUPPL223
      I2=2                                                              SUPPL224
74    IF(OMS(I1).GT.OMS(I2)) GO TO 75                                   SUPPL225
      MINI=I1                                                           SUPPL226
      MIDI=I2                                                           SUPPL227
      GO TO 76                                                          SUPPL228
75    MINI=I2                                                           SUPPL229
      MIDI=I1                                                           SUPPL230
76    SORT(1)=OMS(MINI)                                                 SUPPL231
      SORT(2)=OMS(MIDI)                                                 SUPPL232
      SORT(3)=OMS(MAXI)                                                 SUPPL233
      DO 77 I=1,3                                                       SUPPL234
      OMS(I)=SORT(I)                                                    SUPPL235
77    OMEGA(I)=DSQRT(CMS(I))                                            SUPPL236
      DO 302 I=1,3                                                      SUPPL237
3C2   ALPHA(I,I)=1.                                                     SUPPL238
      DENB=BETA(2,1)*BETA(3,2)-BETA(3,1)*(BETA(2,2)-OMS(1))             SUPPL239
      ALPHA(1,2)=(BETA(1,2)*BETA(3,1)-BETA(3,2)*(BETA(1,1)-OMS(1)))/DENBSUPPL240
      ALPHA(1,3)=((BETA(2,2)-OMS(1))*(BETA(1,1)-OMS(1))-BETA(1,2)*BETA(2SUPPL241
     1,1))/DENB                                                         SUPPL242
      CHK(1)=BETA(1,3)*ALPHA(1,1)+BETA(2,3)*ALPHA(1,2)+(BETA(3,3)-OMS(1)SUPPL243
     1)*ALPHA(1,3)                                                      SUPPL244
      DENB=BETA(3,2)*(BETA(1,1)-CMS(2))-BETA(3,1)*BETA(1,2)             SUPPL245
      ALPHA(2,1)=(BETA(3,1)*(BETA(2,2)-OMS(2))-BETA(2,1)*BETA(3,2))/DENBSUPPL246
      ALPHA(2,3)=(BETA(2,1)*BETA(1,2)-(BETA(1,1)-OMS(2))*(BETA(2,2)-OMS(SUPPL247
     12)))/DENB                                                         SUPPL248
      CHK(2)=BETA(1,3)*ALPHA(2,1)+BETA(2,3)*ALPHA(2,2)+(BETA(3,3)-OMS(2)SUPPL249
     1)*ALPHA(2,3)                                                      SUPPL250
      DENB=BETA(2,3)*(BETA(1,1)-CMS(3))-BETA(1,3)*BETA(2,1)             SUPPL251
      ALPHA(3,1)=(BETA(2,1)*(BETA(3,3)-OMS(3))-BETA(3,1)*BETA(2,3))/DENBSUPPL252
      ALPHA(3,2)=(BETA(3,1)*BETA(1,3)-(BETA(1,1)-OMS(3))*(BETA(3,3)-OMS(SUPPL253
     13)))/DENB                                                         SUPPL254
      CHK(3)=BETA(1,2)*ALPHA(3,1)+(BETA(2,2)-OMS(3))*ALPHA(3,2)+BETA(3,2SUPPL255
     1)*ALPHA(3,3)                                                      SUPPL256
      WRITE(6,488)                                                      SUPPL257
      WRITE(6,489) (I,OMEGA(I),BETA(I,1),BETA(I,2),BETA(I,3),ALPHA(I,1),SUPPL258
     1ALPHA(I,2),ALPHA(I,3),CHK(I),I=1,3)                               SUPPL259
      SORT(1)=1.                                                        SUPPL260
      SORT(2)=0.                                                        SUPPL261
      SORT(3)=0.                                                        SUPPL262
      DO 432 J=1,3                                                      SUPPL263
      GO TO (381,382,383), J                                            SUPPL264
382   SORT(1)=0.                                                        SUPPL265
      SORT(2)=1.                                                        SUPPL266
      SORT(3)=0.                                                        SUPPL267
      GO TO 381                                                         SUPPL268
3E3   SORT(1)=0.                                                        SUPPL269
      SORT(2)=0.                                                        SUPPL270
      SORT(3)=1.                                                        SUPPL271
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381  DO 384 I=1,3                                                             SUPPL272
     DO 384 K=1,3                                                             SUPPL273
384  DELTA(I,K)=ALPHA(I,K)                                                    SUPPL274
     CALL ALSOL(3,DELTA,SQRT,3)                                               SUPPL275
     DO 431 I=1,3                                                             SUPPL276
431  GAMMA(I,J)=SQRT(I)                                                       SUPPL277
432  CONTINUE                                                                 SUPPL278
     WRITE(6,11)                                                              SUPPL279
     WRITE(6,12) (I,GAMMA(I,1),GAMMA(I,2),GAMMA(I,3),I=1,3)                   SUPPL280
     AMPLU = XMUAVB * (1. - ROVB**3) / (1. - ROVB**4) * 1.333333333333D0SUPPL284
     SA = SMALS * S1LB + RM * S2LB * HIGHS                                    SUPPL285
     SB = SMALS * S1LB**2 + RM * S2LB**2 * HIGHS                              SUPPL286
     DEL(1,1) =  XMUVB * (1. - ROVB**4) / (4. * (1. - SLAMZ * XBAB**2)  SUPPL287
    A      *  RRDBR * FM11 )                                                  SUPPL288
     DEL(1,2) =  2. * SLAMZ * XBAB * DEL(1,1)                                 SUPPL289
     DEL(1,3) = A1 * (SLAMZ * XBAB ● SB - SA ) / (1. - SLAMZ * XBAB**2)SUPPL290
    A      +   B * HIGHS * S2LB                                               SUPPL291
     DEL(2,1) =  A2 / A1 * DEL(1,1)                                           SUPPL292
     DEL(2,2) =  A2 / A1 * DEL(1,2)                                           SUPPL293
     DEL(2,3) = A2 * (SLAMZ * XBAB  * SB - SA) / (1. - SLAMZ * XBAB**2)SUPPL294
    A      -  B * SMALS * S2LB                                                SUPPL295
     DEL(3,1) = - SLAMZ * XBAB * DEL(1,1) / A1                                SUPPL296
     DEL(3,2) = -2. * SLAMZ ● DEL(1,1) / A1                                   SUPPL297
     DEL(3,3) = (BDBR / RRDBR)**2 +  SLAMZ * (XBAB * SA - SB) /               SUPPL298
    A      (1. - SLAMZ * XBAB**2)                                             SUPPL299
     CMPA(2) = CMPAVB                                                         MAIN
     CL(2) = CLVB                                                             MAIN
          NDIMC= 60
        COSPSI=  1.
        SINPSI= 0.
     TO = ATOVB + ATCVB  * COS PSI   + ATSVB * SIN PSI
        TOT(1)= TO - ATOVB
       DO 50 I=1,3
 50     SMALLG(I)= DEL(I,1) * CLVB + DEL( I,2) * CMPAVB
        DO 51  I=1,3
        GCAP(I,1)=0.
      DO 52  J=1,3
          YPR(I,J)=0.
 52       GCAP(I,1)    =  GCAP(I,1) + ALPHA(I,J) * SMALLG(J)
        GCAP(I,2)= GCAP(I,1)
        Y(I,1)= GCAP(I,1) / CMS(I)
 51       Y(I,2) = Y(I,1)
        IF ( PLOTOP .LT. 0.)
    1 WRITE( 6,9000) TO, Z, TOPR, ZPR, Y, YPR, DEL, SMALLG
 9000  FORMAT(//'   TO=', 1P1E13.6, '  Z=', 1P3E13.6,' TOPR=', 1P1E13.6
    1 , ' ZPR=', 1P3E13.6 / '  Y=', 1P9E13.6/'  YPR=   ' , 1P9E13.6
    2 / '  DEL=  ', 1P9E13.6/ '  SMALLG=  ', 1P9E13.6//)
      RETURN                                                                  SUPPL300
C                                                                             SUPPL301
C                                                                             SUPPL302
      ENTRY SUPPI (UINF)                                                      SUPPL303
C                                                                             SUPPL304
C                                                                             SUPPL305
      CMPA(3) = CMPA(2)                                                       SUPPL306
      CMPA(2) = CMPAVB                                                        MAIN
      CMPA(1) = 2. * CMPA(2) - CMPA(3)                                  SUPPL308
      CL(3) = CL(2)                                                     SUPPL309
      CL(2) = CLVB                                                      MAIN
      CL(1) = 2. * CL(2) - CL(3)                                        SUPPL311
      PSI =  (BDBR / RRDBR ) * NTIME * DXI                              SUPPL312
      SIN PSI = SIN(PSI)                                                SUPPL313
      COS PSI = COS(PSI)                                                SUPPL314
         TOT(2)= TOT(1)
      TO = ATOVB + ATCVB  * COS PSI  + ATSVB * SIN PSI                  SUPPL315
        TOT(1)= TO - ATOVB
      TO PR = (BDBR/ RRDBR) ● (ATSVB * COS PSI - ATCVB * SIN PSI)       SUPPL316
      DO 60 K = 1, 2
      DO 64 I = 1, 3                                                    SUPPL317
64    SMALL G(I) = UINF **2 * (DEL(I,1) * CL(K) +  DEL(I,2) * CMPA(K))
     A     +    DEL(I,3) * TOT(K)                                       SUPPL319
      DO 65 I = 1, 3                                                    SUPPL320
      G CAP(I, K) = 0.
      DO 65 J = 1, 3                                                    SUPPL322
65    G CAP(I, K)  = GCAP(I, K) + ALPHA(I,J) * SMALLG(J)
60         CONTINUE
      DO 62 I = 1, 3                                                    SUPPL328
      Y(I,2) = Y(I,1)                                                   SUPPL329
      YPR(I,2) = YPR(I,1)                                               SUPPL330
      WDXI    = OMEGA(I) * DXI                                          SUPPL331
      SWDXI     = SIN(WDXI)                                             SUPPL332
      CWDXI     = COS(WDXI)                                             SUPPL333
      Y(I,1) = Y(I,2) * CWDXI  + YPR(I,2) * SWDXI /OMEGA(I)             SUPPL334
     A  +((GCAP(I,2) - GCAP(I,1)) * (SWDXI - WDXI * CWDXI) / WDXI       SUPPL335
     B   + GCAP(I,1) * (1. - CWDXI)) / OMEGA(I)**2                      SUPPL336
62    YPR(I,1) = YPR(I,2) * CWDXI - OMEGA(I) * Y(I,2) * SWDXI           SUPPL337
     A   +  ( (GCAP(I,2) - GCAP(I,1) ) * (WDXI * SWDXI + CWDXI - 1.)    SUPPL338
     B       / WDXI  + GCAP(I,1) * SWDXI) / OMEGA(I)                    SUPPL339
      DC 61 I = 1, 3                                                    SUPPL340
      Z(I) = 0.                                                         SUPPL341
      ZPR(I) = 0.                                                       SUPPL342
      DO 61 J = 1, 3                                                    SUPPL343
      Z(I) = Z(I) + GAMMA(I,J) * Y(J,1)                                 SUPPL344
61    ZPR(I) = ZPR(I) + GAMMA(I,J) * YPR(J,1)                           SUPPL345
      ALPH1 = TO + Z(3)                                                 SUPPL346
      ALPH2 = TO PR + ZPR(3)                                            SUPPL347
      HEAVE =  - ZPR(1)  - ZPR(2)
         IF ( PLOTOP .LT. 0.)
     1 WRITE( 6,9000) TO, Z, TOPR, ZPR, Y, YPR, DEL, SMALLG
     2 , TOT
      RETURN                                                            SUPPL351
1     FORMAT(5F10.4)                                                    SUPPL352
2     FORMAT(5F10.4)                                                    SUPPL353
3     FORMAT(1H1,10X,'ITERATION FOR XBAR DIVERGED')                     SUPPL354
4     FORMAT(1H1,5X,4HF1 =E13.5,5X,4HF2 =E13.5,5X,4HF3 =E13.5//5X,4HRM =SUPPL355
     1E13.5////)                                                        SUPPL356
5     FORMAT(5X,5HM11 =E13.5,5X,5HM22 =E13.5,5X,5HM33 =E13.5,5X,5HM13 =ESUPPL357
     113.5,5X,5HM23 =E13.5/)                                            SUPPL358
6     FORMAT(5X,5HT11 =E13.5,5X,5HT22 =E13.5,5X,5HT33 =E13.5,5X,5HT13 =ESUPPL359
     113.5,5X,5HT23 =E13.5///)                                          SUPPL360
7     FORMAT(20X,6HXB/R =E13.5,10X,6HXB/B =E13.5/20X,6HL1/R =E13.5,10X,6SUPPL361
     1HL1/B =E13.5/20X,6HL2/R =E13.5,10X,6HL2/B =E13.5/9X,7HK1/M1 =E13.5SUPPL362
     1/9X,7HK2/M2 =E13.5)                                                SUPPL363
41    FCRMAT(//10X,5HB/R =E13.5,20X,6HRR/R =E13.5///)                    SUPPL364
44    FORMAT(1H1,20X,'POLYNOMIAL COEFFICIENTS'///7X,5HPOWER,12X,5HBLADE,SUPPL365
     126X,3H2-D/)                                                        SUPPL366
46    FORMAT(I10,2D30.9)                                                 SUPPL367
47    FORMAT(1H1,20X,'ROOTS OF POLYNOMIALS'///30X,'BLADE',60X,'2-D'/20X,SUPPL368
     14HREAL,21X,4HIMAG,31X,4HREAL,21X,4HIMAG/)                          SUPPL369
49    FORMAT(2D25.9,10X,2D25.9)                                          SUPPL370
11    FORMAT(/////9X,1HI,15X,10HGAMMA(I,1),15X,10HGAMMA(I,2),15X,10HGAMMSUPPL371
     1A(I,3)/)                                                           SUPPL372
12    FORMAT(I10,3E25.5)                                                 SUPPL373
488   FORMAT(1H1,8X,1HI,7X,5HOMEGA,4X,9HBETA(I,1),4X,9HBETA(I,2),4X,9HBESUPPL374
     1TA(I,3),3X,10HALPHA(I,1),3X,10HALPHA(I,2),3X,10HALPHA(I,3),8X,3HCHSUPPL375
     1K//)                                                               SUPPL376
489   FORMAT(I10,8E13.5)                                                 SUPPL377
721   FORMAT(///10X,5HFR1 =E13.5,10X,5HFR2 =E13.5,10X,5HFR3 =E13.5//10X,SUPPL378
     14HSA =E13.5,10X,4HSB =E13.5///)                                    SUPPL379
      END
      SUBROUTINE SETUPS                                                     SETUPS 1
C                                                                           SETUPS 2
      IMPLICIT REAL*8 (A-H,O-Z)                                             SETUPS 3
C                                                                           SETUPS 4
C                                                                           SETUPS 5
      REAL   FTVB,  FPVB,  FPPRVB,  DIDRVB,  XMVB,  DELVB,  XMUVB,          SETUPS 6
     A     FOVB,  XMUAVB,  ATOVB,  ATCVB,  ATSVB,  ROVB,  RVB,  MVB         SETUPS 7
      REAL   ELSIG,  DXI,  REB,  RDBB,  FRZ,  ARR,  AMPLU,  FREQU,          SETUPS 8
     A   ALPH1,  ALPH2,  HEAVE,  AROT,  FREQF,  PHIH,        RY1,  DRY,     SETUPS 9
     B   Y,  TEST,  UPRIM,  XU,  YU,  XL,  YL,  ER1,  ER2,  ER3,  BDBR,     SETUPS10
     C      RRDBR                                                           SETUPS11
     H,   CMPA, CMPAS, BARG, EM1, HVOR,        SSPA, SVOR, TORF, X1VOR
     I, PLOTOP, PSILOW, PSIUP
C                                                                           SETUPS12
      INTEGER  TABLE(7, 80) /560 * ' '/
C                                                                           SETUPS14
C                                                                           SETUPS15
      COMMON /BL1/       NTIME                                              SETUPS16
C                                                                           SETUPS17
      COMMON /INPTVB/    FTVB(64),   FPVB(64),   FPPRVB(64),   DIDRVB(64),  SETUPS18
     A       XMVB(64),   DELVB,      XMUVB,      FOVB,    XMUAVB,           SETUPS19
     B       ATOVB,      ATCVB,       ATSVB,       ROVB,          RVB(64),  SETUPS20
     C       MVB(64),    NVB                                                SETUPS21
C                                                                           SETUPS22
      COMMON /INPUTS/    NSBL,      NZ,        NOFF,      NGAM,      NSIG,  SETUPS23
     A         NCOI,     NCORD,     LOWER,     MSTOP,     MAXT,      MOTR,  SETUPS24
     B         NOTBL,    INDV,      ELSIG,     DXI,       REB,       RDBB,  SETUPS25
     C         FRZ,      ARR,       AMPLU,     FREQU,     ALPH1,     ALPH2, SETUPS26
     D         HEAVE,    AROT,      FREQF,     PHIH,      NY,        RY1,   SETUPS27
     E         DRY,      Y(100),    TEST,      UPRIM,     XU(30),    YU(30),SETUPS28
     F         XL(30),   YL(30),    ER1,       ER2,       ER3,       BDBR,  SETUPS29
     G         RRDBR                                                        SETUPS30
     H,   CMPA, CMPAS, BARG, EM1, HVOR, NVOR, SSPA, SVOR, TORF, X1VOR
     I, PLOTOP, PSILOW, PSIUP
     J , NOUT
C                                                                           SETUPS31
C                                                                           SETUPS32
C                                                                           SETUPS33
      CALL WHERE(TABLE)                                                     SETUPS34
      CALL ZEROIN                                                           SETUPS35
C                                                                           SETUPS36
C                                                                           SETUPS37
      CALL SETUP('ALPH1   ',4, ALPH1               )                        SETUPS38
      CALL SETUP('ALPHA1  ',4, ALPH1               )                        SETUPS39
      CALL SETUP('ALPH2   ',4, ALPH2               )                        SETUPS40
      CALL SETUP('ALPHA2  ',4, ALPH2               )                        SETUPS41
      CALL SETUP('AMPLU   ',4, AMPLU               )                        SETUPS42
      CALL SETUP('ARR     ',4, ARR                 )                        SETUPS43
      CALL SETUP('AROT    ',4, AROT                )                        SETUPS44
      CALL SETUP('ATOVB   ',4, ATOVB               )                        SETUPS45
      CALL SETUP('ATCVB   ',4, ATCVB               )                        SETUPS46
      CALL SETUP('ATSVB   ',4, ATSVB               )                        SETUPS47
      CALL SETUP('BARG    ',4,  BARG               )
      CALL SETUP('BDBR    ',4,  BDBR               )                        SETUPS48
      CALL SETUP('CMPA    ',4,  CMPA               )
      CALL SETUP('CMPAS    ',4,  CMPAS                )
      CALL SETUP('DELVB    ',4,  DELVB                )                  SETUPS49
      CALL SETUP('DIDRVB   ',4,  DIDRVB, 64           )                  SETUPS50
      CALL SETUP('DRY      ',4, DRY                   )                  SETUPS51
      CALL SETUP('DXI      ',4, DXI                   )                  SETUPS52
      CALL SETUP('ELSIG    ',4, ELSIG                 )                  SETUPS53
      CALL SETUP('EMI      ',4,  EMI                  )
      CALL SETUP('ER1      ',4,  ER1                  )                  SETUPS54
      CALL SETUP('ER2      ',4,  ER2                  )                  SETUPS55
      CALL SETUP('ER3      ',4,  ER3                  )                  SETUPS56
      CALL SETUP('FPVB     ',4,  FPVB,    64          )                  SETUPS57
      CALL SETUP('FPPRVB   ',4,  FPPRVB, 64           )                  SETUPS58
      CALL SETUP('FRZ      ',4, FRZ                   )                  SETUPS59
      CALL SETUP('FREQU    ',4, FREQU                 )                  SETUPS60
      CALL SETUP('FREQF    ',4, FREQF                 )                  SETUPS61
      CALL SETUP('FTVB     ',4,  FTVB,    64          )                  SETUPS62
      CALL SETUP('FOVB     ',4,  FOVB                 )                  SETUPS63
      CALL SETUP('HEAVE    ',4, HEAVE                 )                  SETUPS64
      CALL SETUP('HVOR     ',4,  HVOR                 )
      CALL SETUP('INDV     ',4, INDV                  )                  SETUPS65
      CALL SETUP('LOWER    ',4, LOWER                 )                  SETUPS66
      CALL SETUP('MAXT     ',4, MAXT                  )                  SETUPS67
      CALL SETUP('MOTR     ',4, MOTR                  )                  SETUPS68
      CALL SETUP('MSTOP    ',4, MSTOP                 )                  SETUPS69
      CALL SETUP('MVB      ',4,  MVB ,    64          )                  SETUPS70
      CALL SETUP('NCOI     ',4, NCOI                  )                  SETUPS71
      CALL SETUP('NCORD    ',4, NCORD                 )                  SETUPS72
      CALL SETUP('NGAM     ',4, NGAM                  )                  SETUPS73
      CALL SETUP('NOFF     ',4, NOFF                  )                  SETUPS74
      CALL SETUP('NOTBL    ',4, NOTBL                 )                  SETUPS75
         CALL SETUP('NOUT     ', 4, NOUT)
      CALL SETUP('NSBL     ',4, NSBL                  )                  SETUPS76
      CALL SETUP('NSIG     ',4, NSIG                  )                  SETUPS77
      CALL SETUP('NVB      ', 4, NVB)                                    SETUPS78
      CALL SETUP('NVOR     ',4,  NVOR                 )
      CALL SETUP('NY       ',4, NY                    )                  SETUPS79
      CALL SETUP('NZ       ',4, NZ                    )                  SETUPS80
      CALL SETUP('PHIH     ',4, PHIH                  )                  SETUPS81
      CALL SETUP('PLOTOP   ', 4, PLOTOP)
      CALL SETUP('PSILOW   ', 4,  PSILOW)
      CALL SETUP('PSIUP    ',  4, PSIUP)
      CALL SETUP('RVB      ', 4,  RVB, 64 )                              SETUPS82
      CALL SETUP('RDBB     ',4, RDBB                  )                  SETUPS83
      CALL SETUP('REB      ',4, REB                   )                  SETUPS84
      CALL SETUP('RRDBR    ',4,  RRDBR                )                  SETUPS85
      CALL SETUP('ROVB     ',4, ROVB                  )                  SETUPS86
      CALL SETUP('RYI      ',4, RYI                   )                  SETUPS87
      CALL SETUP('SSPA     ',4,  SSPA                 )
      CALL SETUP('SVOR     ',4,  SVOR                 )
      CALL SETUP('TEST     ',4, TEST                  )                  SETUPS88
      CALL SETUP('TORF     ',4,  TORF                 )
      CALL SETUP('UPRIM    ',4, UPRIM                 )                  SETUPS89
      CALL SETUP('XIVOR    ',4,  XIVOR                )
      CALL SETUP('XL       ',4,  XL,  30              )                  SETUPS90
      CALL SETUP('XMVB     ',4,  XMVB,    64          )                  SETUPS91
      CALL SETUP('XMUVB    ',4,  XMUVB              )                   SETUPS92
      CALL SFTUP('XMUAVB   ',4, XMJAVB              )                   SETUPS93
      CALL SETUP('XU       ',4,  XU,  30            )                   SETUPS94
      CALL SETUP('Y        ',4, Y,  100             )                   SETUPS95
      CALL SETUP('YL       ',4,  YL,  30            )                   SETUPS96
      CALL SETUP('YU       ',4,  YU,  30            )                   SETUPS97
C                                                                       SETJPS98
C                                                                       SETUPS99
C                                                                       SETUP100
C                                                                       SFTUP101
C                                                                       SETUP102
C                                                                       SETUP103
C                                                                       SFTUP104
         PSILOW= 1.E10
         PSIUP=      -1.E10
        PLOTOP = 1.
            NOUT= 0
      RETURN                                                            SETUP105
C                                                                       SETUP106
      END
      SUBROUTINE BLC(X,Y,MST,MEND,NY,RY,DRY,DXI,REB,UPRIM,FLAM,XFLAM,TESBLC
     1T,U,SCALE,UE,UC,V,XSEP,USEP,DISS,THETS,LOWER,LAMQ,MSEP,XC,USAV,SCABLC
     1LS,NITS,NTIME, NOTBL, XTEST, NZ, NOUT )
C                                                                       BLC
C   PROGRAM FOR ANALYZING LAMINAR AND TURBULENT BOUNDARY LAYERS         BLC
C   BY THE METHOD OF FINITE DIFFERENCES.  IF THE INTEGER LAMQ           BLC
C   IS GREATER THAN ZERO, THE BOUNDARY LAYER IS LAMINAR.                BLC
C                                                                       BLC
      COMMON /BL1/     NDUMMY, NDIMC , ISTD
      DIMENSION USAV(300,100),SCALS(300)                                BLC
      DIMENSION X(300),Y(100),UE(300,3),UC(100,3),V(100,2),XC(300)      BLC
      DIMENSION SD(100),SE(100),SF(100),VISC(100,2),GRAD(100)           BLC
      DIMENSION A(100),B(100),C(100),D(100),F(100)                      BLC
      DIMENSION ALPHA(100),BETA(100),GAMMA(100),DELTA(100)              BLC
      DIMENSION SCALE(300,2),VAR1(100),VAR2(100)                        BLC
      DIMENSION FLAM(10),XFLAM(10),YB1(100),YB2(100)                    BLC
      DIMENSION U(300,100,2)                                            BLC
      DIMENSION CAPG(100),CAPH(100),CAPJ(100),CAPK(100)                 BLC
      DOUBLE PRECISION AP(100),BP(100),CP(100),DP(100),FP(100),UP(100)  BLC
 10   FORMAT(1H1,41X,36H  ANALYSIS OF LAMINAR BOUNDARY LAYER///51X,12HTIBLC
     1ME STEP NOI3//51X,12HITERATION NOI3///4X,1HM,8X,1HX,13X,2HXC,12X,2BLC
     1HUE,10X,6H-DP/DX,9X,5HDELTA,9X,5HDISPL,9X,5HTHETA,9X,5HSHEAR/)    BLC
 11   FORMAT(1H1,41X,36HANALYSIS OF TURBULENT BOUNDARY LAYER///51X,12HTIBLC
     1ME STEP NOI3//51X,12HITERATION NOI3///4X,1HM,8X,1HX,13X,2HXC,12X,2BLC
     1HUE,10X,6H-DP/DX,9X,5HDELTA,9X,5HDISPL,9X,5HTHETA,9X,5HSHEAR,4X,  BLC
     3 'I'/)
 12   FORMAT(I5,8E14.4,I3)
 20   FORMAT(1H1,2X,3HM =I4//2X,3HX =E14.5//2X, 4HUE =E14.5,10X,17H-(1/RBLC
     1HO)(DP/DX) =E14.5,10X,5HREB =E14.5,10X,4HU* =E14.5///)            BLC
 24   FORMAT(2X,25HPHYSICAL           DELTA =E14.5,8X,12HDELTA STAR =E14.BLC
     15,8X,7HTHETA =E14.5//2X,25HTRANSFORMED         DELTA =E14.5,8X,12HDEBLC
     1LTA STAR =E14.5,8X,7HTHETA =E14.5///)                             BLC
 21   FORMAT(25X,1HY,19X,1HU,19X,1HV,16X,5HDU/DY,14X,6HNUE/NU/)         BLC
 22   FORMAT(10X,5E20.5)                                                BLC
 23   FORMAT(//30X,17HSEPARATION AT X =E13.5,6H, XC =E13.5)             BLC
 25   FORMAT(///40X,12HWALL SHEAR =E14.5//)                             BLC
 30   FORMAT(//50X,17HTRANSITION AT X =E14.5)                           BLC
 35   FORMAT(/20X,35HSCALE CHANGE - Y-MAX INCREASED FROME12.4,3H TOE12.4BLC
     1/)                                                                BLC
 810  FORMAT(10X,7HAT STEPI3,22H, THE WALL GRADIENT ISE12.4)            BLC
      BCON = 1.5/DXI                                                    BLC
      FCON = 1./(2.*DXI)                                                BLC
          IF( ISTD.NE. 1) GO TO 900
        DXI=1.E30
          BCON=0.
          FCON= 0.
 900      CONTINUE
      MOUT=6                                                            BLC
      MTRAN=-1                                                          BLC
      YSUB2=Y(2)                                                        BLC
      MST2 = MST - 2                                                    BLC
      MST1=MST-1                                                        BLC
           NOUT1= NOUT +1
         MST1MD=  MOD(  MST1, NOUT1)
         MAXIT=0
      GO TO (543,550),LOWER                                             BLC   44
  543 IF(LAMQ) 544,544,545                                              BLC   45
  544 WRITE(MOUT,11) NTIME,NITS                                         BLC   46
      GO TO 550                                                         BLC   47
  545 WRITE(MOUT,10) NTIME,NITS                                         BLC   48
  550 CONTINUE                                                          BLC   49
      YTR = SQRT(REB)                                                   BLC   50
      UC(1,1) = 0.                                                      BLC   53
      V(1,1) = 0.                                                       BLC   54
      NV = NY - 2                                                       BLC   55
      NVM1 = NV - 1                                                     BLC   56
      NVP1 = NV + 1                                                     BLC   57
      CALL YDIFF(NY,ALPHA,BETA,GAMMA,DELTA,SD,SE,SF,C2,C3,C4,Y)         BLC   58
      DO 41 N=1,NVP1                                                    BLC   59
      VISC(N,1) = 1.                                                    BLC   60
   41 VISC(N,2) = 1.                                                    BLC   61
      DO 42 M=MST2,MST1                                                 BLC   62
      L = MST1-M+2                                                      BLC   63
      DO 50 N=1,NV                                                      BLC   64
   50 GRAD(N+1) = SD(N+1)*UC(N+2,L)+SE(N+1)*UC(N+1,L)-SF(N+1)*UC(N,L)   BLC   65
      GRAD(1) = C2*UC(2,L)+C3*UC(3,L)+C4*UC(4,L)                        BLC   66
      MM=M-1                                                            BLC   67
      CALL PGRAD(MM,X,UE,DXI,PRESS,SA,SB,SC,SR,SS)                      BLC   68
      DO 456 N=1,NY                                                     BLC   69
  456 UC(N,1)=UC(N,L)                                                   BLC   70
      CALL SETIT(LAMQ,M,NV,REB,X,Y,UC,PRESS,GRAD,DELT,DISP,THETA,VISC,MTBL3   71
     1RAN)                                                              BLC   72
   42 CONTINUE                                                          BLC   73
      MEND1 = MEND - 1                                                  BLC   74
      GRADS=GRAD(1)                                                     BLC   75
      GRADSS=GRAD(1)                                                    BLC   76
C                                                                       BLC   77
C   THE MAIN CALCULATION STARTS HERE.                                   BLC   78
C                                                                       BLC   79
      DO 99 M=MST1,MEND1                                                BLC   80
      ITER=0                                                            BLC   81
      WALLG=0.                                                          BLC   82
      MP1=M+1                                                           BLC   83
      DELTP = DELT/YTR                                                  BLC   84
      DISPT = DISP*YTR                                                  BLC   85
      THETT = THETA*YTR                                                 BLC   86
      SHEAR = GRAD(1)/YTR                                               BLC   87
         IF( MOD(M,  NOUT1).NE. MST1MD) GO TO 225
      GO TO (561,562),LOWER                                             BLC   88
  561 WRITE(MOUT,12) M,X(M),XC(M),UE(M,1),PRESS,DELTP,DISP,THETA, SHEAR BLC   89
     1 , MAXIT
      GO TO 225                                                         BLC   90
  562 WRITE(MOUT,20) M,X(M),UE(M,1),PRESS,REB,UPRIM                     BLC   91
      WRITE(MOUT,24) DELTP,DISP,THETA,DELT,DISPT,THETT                  BLC   92
      WRITE(MOUT,21)                                                    BLC   93
      WRITE(MOUT,22) (Y(N),UC(N,2),V(N,1),GRAD(N),VISC(N,1),N=1,NVP1)   BLC   94
      WRITE(MOUT,25) SHEAR                                              BLC   95
  225 IF(GRADSS-GRADS-1.E-6) 229,229,408                                BLC   96
  408 XSX=X(M-2)+(X(M-1)-X(M-2))*GRADSS/(GRADSS-GRADS)                  BLC   97
      IF(XSX-X(M)) 409,409,229                                          BLC   98
  409 WFS=(XSX-X(M-1))/(X(M)-X(M-1))
      GO TO 224
  229     IF ( GRAD(1) )  227, 227, 273
  273   IF (DISP .GT. 0. .AND. THETA .GT. 0.) GO TO 223
  283    CONTINUE
        XSEP= XC(M-1)
         USEP=UE(M-1,1)
          XBL=X(M-1)
           WRITE(MOUT,23) XBL, XSEP
          RETURN
  227 WFS=GRADS/(GRADS-GRAD(1))
  224 WFS1=1.-WFS
      XSEP=WFS1*XC(M-1)+WFS*XC(M)
      XBL=WFS1*X(M-1)+WFS*X(M)
      USEP=WFS1*UE(M-1,1)+WFS*UE(M,1)
      WFP=(XBL-X(M-2))/(X(M-1)-X(M-2))
      WFP1=1.-WFP
      DISS=DISSS*WFP1+DISS*WFP
      THETS=THETSS*WFP1+THETS*WFP
      WRITE(MOUT,23) XBL,XSEP
      IF(LAMQ.EQ.0.AND.M.LT.MTRAN+5) LAMQ=1
      GO TO 222
  223 CONTINUE
         IF(  NOTBL .EQ. 2 .AND. NITS  .GT. 1 .AND. M.GT. NZ .AND.
     1 XC(M) .GT. XTEST) GO TO 283
      IF(LAMQ) 801,801,802
  802      IF( NOTBL .EQ. 2) GO TO 801
      CALL TRANS(UPRIM,PRESS,THETA,REB,UC,NY,FLAM,XFLAM,LAMQ)
      IF(LAMQ) 805,805,801
  805 WRITE(MOUT,30) X(M)
      MTRAN = M+1
  801 CONTINUE
      IF(Y(NV)-DELT) 620,641,641
  620 RY=RY+DRY
C
C  RESCALING CALCULATION STARTS HERE.
C
      DO 632 N=1,NY
      YB1(N) = Y(N)
      VAR1(N) = UC(N,2)
  632 VAR2(N) = UC(N,3)
      CALL YSET(RY,YSUB2,NY,Y)
      WRITE(MOUT,35) YB1(NY),Y(NY)
      DO 633 N=2,NVP1
      YIN = Y(N)
      CALL TERP(YIN,YB1,VAR1,NY,UPAS1)
      UC(N,2) = UPAS1
      CALL TERP(YIN,YB1,VAR2,NY,UPAS2)
  633 UC(N,3) = UPAS2
      CALL YDIFF(NY,ALPHA,BETA,GAMMA,DELTA,SD,SE,SF,C2,C3,C4,Y)
      IF(LAMQ) 700,700,701
  700 DO 635 N=2,NVP1
      VAR1(N) = VISC(N,1)
  635 VAR2(N) = VISC(N,2)
      DO 636 N=2,NVP1
      YIN = Y(N)                                                        BLC  144
      CALL TERP(YIN,YB1,VAR1,NVP1,UPAS1)                                BLC  145
      VISC(N,1) = UPAS1                                                 BLC  146
      CALL TERP(YIN,YB1,VAR2,NVP1,UPAS2)                                BLC  147
  636 VISC(N,2) = UPAS2                                                 BLC  148
  7C1 DC 637 N=2,NVP1                                                   BLC  149
      VAR1(N) = V(N,1)                                                  BLC  150
  637 VAR2(N) = V(N,2)                                                  BLC  151
      DO 638 N=2,NVP1                                                   BLC  152
      YIN = Y(N)                                                        BLC  153
      CALL TERP(YIN,YB1,VAR1,NVP1,UPAS1)                                BLC  154
      V(N,1) = UPAS1                                                    BLC  155
      CALL TERP(YIN,YB1,VAR2,NVP1,UPAS2)                                BLC  156
  638 V(N,2) = UPAS2                                                    BLC  157
  641 CCNTINUF                                                          BLC  158
C                                                                       BLC  159
C  RESCALING CALCULATICN ENDS HERE.                                     BLC  160
C                                                                       BLC  161
      CALL PGRAD(M,X,UE,DXI,PRESS,SA,SB,SC,SR,SS)                       BLC  162
C                                                                       BLC  163
C   RECURSION RELATICNS ARE SET UP HERE.                                BLC  164
C                                                                       BLC  165
        IF (ISTD.EQ. 1) GO TC 820
      IF(SCALE(M+1,1)-1.) 522,522,521                                   BLC  166
  521 IF(SCALE(M+1,2)-1.) 522,522,523                                   BLC  167
  522 LACKU=1                                                           BLC  168
      FACU1=UE(M+1,2)/UE(M+1,1)                                         BLC  169
      FACU2=UE(M+1,3)/UE(M+1,1)                                         BLC  170
      GO TO 820                                                         BLC  171
  523 LACKU=2                                                           BLC  172
      DO 610 NN=1,NY                                                    BLC  173
      VAR1(NN) = U(M+1,NN,1)                                            BLC  174
  610 VAR2(NN) = U(M+1,NN,2)                                            BLC  175
      CALL YSET(SCALE(M+1,1),YSUB2,NY,YB1)                              BLC  176
      CALL YSET(SCALE(M+1,2),YSUB2,NY,YB2)                              BLC  177
  820 DO 88 N=2,NV                                                      BLC  178
      CALL CAPS(ITER,N,CAPG,CAPH,CAPJ,CAPK,SR,SS,SD,SE,SF,VISC,V,UC)    BLC  179
      A(N)=-SF(N)*CAPG(N)-DELTA(N)*CAPH(N)+SF(N)*CAPJ(N)                BLC  180
      B(N)=BCON+SA*CAPK(N)+SF(N)*CAPG(N)-GAMMA(N)*CAPH(N)-SE(N)*CAPJ(N) BLC  181
      C(N)=SD(N)*CAPG(N)-BETA(N)*CAPH(N)-SD(N)*CAPJ(N)                  BLC  182
      D(N) = -ALPHA(N)*CAPH(N)                                          BLC  183
         IF(ISTD .EQ. 1) GO TO 576
      GO TO (574,575),LACKU                                             BLC  184
  574 UPAS1=FACU1*UC(N,1)                                               BLC  185
      UPAS2=FACU2*UC(N,1)                                               BLC  186
      GO TO 576                                                         BLC  187
  575 YIN = Y(N)                                                        BLC  188
      CALL TERP(YIN,YB1,VAR1,NY,UPAS1)                                  BLC  189
      CALL TERP(YIN,YB2,VAR2,NY,UPAS2)                                  BLC  190
  576 F(N) = PRESS+FCON*(4.*UPAS1-UPAS2)+CAPK(N)*(SB*UC(N,2)-SC*UC(N,3))BLC  191
   88 CONTINUE                                                          BLC  192
C                                                                       BLC  193
C    SOLUTION FOR VELDCITY PROFILE STARTS HERE.                         BLC  194
C                                                                       BLC  195
      DO 89 N=2,NV                                                      BLC  196
      AP(N) = A(N)
      BP(N) = B(N)
      CP(N) = C(N)
      DP(N) = D(N)
 89   FP(N) = F(N)
      DO 77 N=2,NVM1
      CP(N) = CP(N)/BP(N)
      DP(N) = DP(N)/BP(N)
      FP(N) = FP(N)/BP(N)
      BP(N+1) = BP(N+1) - CP(N)*AP(N+1)
      CP(N+1) = CP(N+1) - DP(N)*AP(N+1)
 77   FP(N+1) = FP(N+1) - FP(N)*AP(N+1)
      UP(NY) = UE(M+1,1)
      UP(NVP1) = UP(NY)
      UP(NV) = (FP(NV)-UP(NY)*(DP(NV) + CP(NV)))/BP(NV)
      DO 66 N=3,NV
      NN=NV+2-N
 66   UP(NN) = FP(NN) - DP(NN)*UP(NN+2) - CP(NN)*UP(NN+1)
      DO 65 N=2,NY
 65   UC(N,1) = UP(N)
      IF(ITER) 843,841,843
 841  DO 842 N=2,NVP1
      V(N,2) = V(N,1)
 842  VISC(N,2)=VISC(N,1)
      DISSS=DISS
      DISS=DISP
      THETSS=THETS
      THETS=THETA
      GRADSS=GRADS
      GRADS=GRAD(1)
 843  DO 55 N=2,NVP1
 55   V(N,1) = V(N-1,1)-.5*(Y(N)-Y(N-1))*(SA*(UC(N,1)+UC(N-1,1))-SB*(UC(
     1N,2)+UC(N-1,2))+SC*(UC(N,3)+UC(N-1,3)))
      DO 56 N=1,NV
 56   GRAD(N+1) = SD(N+1)*UC(N+2,1)+SE(N+1)*UC(N+1,1)-SF(N+1)*UC(N,1)
      GRAD(1) = C2*UC(2,1)+C3*UC(3,1)+C4*UC(4,1)
      CALL SETIT(LAMQ,MP1,NV,REB,X,Y,UC,PRESS,GRAD,DELT,DISP,THETA,VISC,
     1MTRAN)
      ITER=ITER+1
      GO TO (830,809),LOWER
 809  WRITE(MOUT,810) ITER,GRAD(1)
 830  IF(ITER-9) 811,811,812
 811  EPW=ABS(GRAD(1)-WALLG)
      IF(WALLG-1.) 120,120,119
 119  EPW=EPW/WALLG
 120  IF(EPW-TEST) 812,814,814
 814  WALLG=GRAD(1)
      GO TO 820
 812  DO 44 N=1,NY
      UC(N,3) = UC(N,2)
      UC(N,2) = UC(N,1)
 44         CONTINUE
              MAXIT=ITER
        IF(ISTD .EQ. 1) GO TO  99
            DO 48  N= 1,NY
```

```
48    USAV(M+1,N)=UC(N,1)
      SCALS(M+1)=RY                                                                BLC  249
99    CONTINUE                                                                     BLC  250
      XSEP=1.1                                                                     BLC  251
      USEP=UE(MX,1)                                                                BLC  252
222   CONTINUE                                                                     BLC  253
      RETURN                                                                       BLC  254
      END
```

```
          SUBROUTINE PLOTSB( PLOTOP   ,   P , L   )
           REAL * 8  ORD(6)
             DIMENSION  P(200,7), TIT1(56)                   , NF(5,4)
      1 , NFP(6)
         DATA   N1 , N2 , NO  , N42
      1 / 1 ,  2  , 0  , 42  /
          DATA  ORD/     ' THETA-P' ,'  TORS  ', ' FLAP-H ', ' BEND-H ',
      1  '   CL   ',    '    CM-A ' /
          IF(PLOTOP .EQ.  0. ) RETURN
           IF(            L .LT. 2) RETURN
           IF ( PLOTOP .EQ. 2.) GO TO 2
          PLOTOP = 2.
             CALL IDFRMV ( 'CRIMI -PETE ', '30',   '5100'   )
  2        CONTINUE
  3       NL=1
            DO   1   J =  1,  6
          CALL  EZPLOT(9.   ,  N1     , N1,  P , P(1,J+1), L  , -N1 ,   N2
      1   ,  N42    ,  1 ,' ' , 12   , ' PSI-DEGREES'   , 8 ,  ORD(  J)
      2   , N1   ,    N1 ,  XL  ,   XU    ,  N1   ,  YL   ,  YU ,N1   , NO , NL)
    1     CONTINUE
           NFP(1)= -1
          NFP(2)= 66
           NFP(3)= 50
          NFP(4)= 50
           NFP(5)= 680
          CALL  EZPLOT(9.   ,  N1     , N1,  P , P(1,2   ), L  , -N1 ,   N2
      1   , N42    ,  1 ,' ' , 12   , ' PSI-DEGREES'   , 8 ,  ORD(  1)
      2   , NFP   ,   N1 ,  XL  ,  XU    ,  N1   ,  YL   ,  YU ,N1, NO, N1)
            NFP(1)= -2
            NFP(2)= 66
             NFP(4)= 350
             NFP(5)= 380
          CALL  EZPLOT(9.   ,  N1     , N1,  P , P(1,6   ), L  , -N1 ,   N2
      1   , N42    ,  1 ,' ' , 12   , '                ' , 8 ,  ORD(  5)
      2   , NFP   ,   N1 ,  XL  ,  XU    ,  N1   ,  YL   ,  YU ,N1, NO, N1)
           NFP(2)= 50
          NFP(4)= 690
           NFP(5)= 40
          CALL  EZPLOT(9.   ,  N1     , N1,  P , P(1,7   ), L  , -N1 ,   N2
      1   , N42    ,  1 ,' ' , 12   , '                ' , 8 ,  ORD(  6)
      2   , NFP   ,   N1 ,  XL  ,  XU    ,  N1   ,  YL   ,  YU ,N1, NO, N1)
           NFP(1)=-1
             NFP(2)= 50
             NFP(3)=50
            NFP(4)=50
             NFP(5)= 680
          CALL  EZPLOT(9.   ,  N1     , N1,  P , P(1,3   ), L  , -N1 ,   N2
      1   , N42    ,  1 ,' ' , 12   , ' PSI-DEGREES'   , 8 ,  ORD(  2)
      2   , NFP   ,   N1 ,  XL  ,  XU    ,  N1   ,  YL   ,  YU ,N1, NO, N1)
             NFP(1)=-2
           NFP(2)= 66
             NFP(4)= 350
          NFP(5)= 380
          CALL  EZPLOT(9.   ,  N1     , N1,  P , P(1,4   ), L  , -N1 ,   N2
      1   , N42    ,  1 ,' ' , 12   , '                ' , 8 ,  ORD(  3)
```

```
2   , NFP   ,    N1 ,   XL   ,   XU    ,   N1   ,   YL   ,   YU ,N1, NO, N1)
      NFP(2)= 50
       NFP(4)= 690
      NFP(5)= 40
    CALL  EZPLOT(9.   ,   N1      , N1,   P , P(1,5  ), L , -N1 ,  N2
1   ,  N42    ,  1 ,' ' , 12  , '                     ' , 8 ,  ORD(  4)
2   , NFP   ,    N1 ,   XL   ,   XU    ,   N1   ,   YL   ,   YU ,N1, NO, N1)
           RETURN
               END
      SUBROUTINE STAG(MX,NY,MSTOP,MST,DXI,RY,DRY,X,Y,UE,UC,V,USAV,SCALS,
     1ISEP)
C   PROGRAM FOR CALCULATING THE BOUNDARY LAYER PROFILE NEAR
C   THE STAGNATION POINT
C
      COMMON /BL1/       NTIME, NDIMC , ISTD
      DIMENSION USAV(300,100),SCALS(300)
      DIMENSION PHIZ(24),PHIP(24),ETAP(24)
      DIMENSION X(300),Y(100),UE(300,3),UC(100,3),V(100,2)
      DIMENSION FF(100),FFP(100)
      DATA ETAP /0.,.2,.4,.6,.8,1.,1.2,1.4,1.6,1.8,2.,2.2,2.4,2.6,2.8,3.
     1,3.2,3.4,3.6,3.8,4.,4.2,4.4,4.6/
      DATA PHIZ /0.,.0233,.0881,.1867,.3124,.4592,.622,.7967,.9793,1.168
     19,1.362,1.5578,1.7553,1.9538,2.153,2.3526,2.5523,2.7522,2.9521,3.1
     1521,3.3521,3.5521,3.7521,3.9521/
      DATA PHIP /0.,.2266,.4145,.5663,.6859,.7779,.8467,.8968,.9323,.956
     18,.9732,.9839,.9905,.9946,.997,.9984,.9992,.9996,.9998,.9999,1.,1.
     1,1.,1./
      BAG=.08
      IF(ISEP) 10,10,5
 5    BAG=.5
 10   FF(1) = 0.
      FFP(1) = 0.
      DO 20 M=1,MX
      IF(UE(M,1)) 20,20,19
 19   MSP = M
      GO TO 21
 20   CONTINUE
 21   ASTAG = (UE(MSP+2,1)-UE(MSP+1,1))/(X(MSP+2)-X(MSP+1))
      IF(ASTAG) 22,22,23
 22   ASTAG=(UE(MSP,1)-UE(MSP-1,1))/(X(MSP)-X(MSP-1))
 23   SQAS = SQRT(ASTAG)
      DELT = 2.6/SQAS
 309  IF(DELT-Y(NY-3)) 311,310,310
 310  RY=RY+DRY
      CALL YSET(RY,Y(2),NY,Y)
      GO TO 309
 311  CONTINUE
      DO 80 N=2,NY
      YET = Y(N)*SQAS
      DO 33 NN=1,24
      IF(YET-ETAP(NN)) 408,408,33
 408  MARK = NN
      GO TO 410
 33   CONTINUE
      FF(N) = YET-.6479
      FFP(N) = 1.
      GO TO 80
 410  FRACT = (YET-ETAP(MARK-1))/(ETAP(MARK)-ETAP(MARK-1))
      FRAC1 = 1.-FRACT
      FF(N) = PHIZ(MARK-1)*FRAC1+PHIZ(MARK)*FRACT
      FFP(N) = PHIP(MARK-1)*FRAC1+PHIP(MARK)*FRACT
 80   CONTINUE
      M1 = MSP-MSTOP
      M2 = MSP+MSTOP
      M=M1-1                                                            STAG  55
50    M=M+1                                                             STAG  56
      MST=M+1                                                           STAG  57
      SCALS(M)=RY                                                       STAG  58
      DO 71 N=1,NY                                                      STAG  59
      UC(N,3) = UC(N,2)                                                 STAG  60
      UC(N,2) = UE(M,1)*EFP(N)                                          STAG  61
      V(N,2) = V(N,1)                                                   STAG  62
      V(N,1) = -SQAS*EF(N)                                              STAG  63
        IF(ISTD .EQ. 1) GO TO  71
      USAV(M,N)=UC(N,2)                                                 STAG  64
71    CONTINUE                                                          STAG  65
      IF(M-M2) 50,55,55                                                 STAG  66
55    IF(UF(M,1)-BAG) 50,50,81                                          STAG  67
81    CONTINUE                                                          STAG  68
      RETURN                                                            STAG  69
      END                                                               STAG  70
      SUBROUTINE ATTPR(PREC,XSIG,NSIG,ASZ,AS,AR,CMAT,RMAT,NGAM,NF,ACAP,T
     1HICK,RDBB,GAMAW,UINF,UDOT,DXI,BCAP)
      DIMENSION XSIG(100),ASZ(30),AS(30,30),AR(30),BCAP(100,3)
      DIMENSION ACAP(30,3),THICK(24),GAMAW(1000)
      DOUBLE PRECISION CMAT(60,60   ),RMAT(130)
      PI=3.14159
      NGP1=NGAM+1
      DO 50 M=1,NGP1
      CMAT(M,1)=ASZ(M)
      RMAT(M)=AR(M)
      DO 25 N=1,NGAM
   25 CMAT(M,N+1)=AS(M,N)
   50 CONTINUE
      CALL ALSOL(NGP1,CMAT,RMAT)
      DO 75 M=1,NGP1
   75 ACAP(M,1)=RMAT(M)
      GAMAW(1)=GAMI(ACAP,DXI,PI)
      SAVE=XSIG(NSIG+1)
      XSIG(NSIG+1)=2.
      CALL CPC(0,NGAM,NF,XSIG,NSIG,XSIG,NSIG,XSIG,NSIG,ACAP,BCAP,THICK,R
     1DBB,GAMAW,UINF,UDOT,1.,SAVE,DXI,PREC)
      XSIG(NSIG+1)=SAVE
      RETURN
      END
      SUBROUTINE UNPOP(NGAM,AR,ALAM,AFACT,RMAT,CMAT,XGAM,AS,ACAP,MX,NZ,NUNPOP   1
     1F,XSIG,BCAP,THICK,RDBB,UINF,XC,UE)                                UNPOP   2
      DIMENSION AR(30),ALAM(30),XGAM(30),AS(30,30),ACAP(30,3),XSIG(100),UNPOP   3
     1BCAP(100,3),THICK(24),XC(300),JE(300,3)                           UNPOP   4
      DOUBLE PRECISION RMAT(130),CMAT(60,60   )                         UNPOP   5
      NGP1=NGAM+1                                                       UNPOP   6
      DO 5 M=1,NGP1                                                     UNPOP   7
      SUB=AR(M)-ALAM(M)*AFACT/3.                                        UNPOP   8
      RMAT(M)=SUB                                                       UNPOP   9
      CMAT(M,1)=1.                                                      UNPOP  10
      CMAT(M,2)=XGAM(M)                                                 UNPOP  11
      DO 5 N=2,NGAM                                                     UNPOP  12
    5 CMAT(M,N+1)=AS(M,N)                                               UNPOP  13
      CALL ALSOL(NGP1,CMAT,RMAT)                                        UNPOP  14
      DO 10 N=1,NGP1                                                    UNPOP  15
   10 ACAP(N,1)=RMAT(N)                                                 UNPOP  16
      DO 15 M=1,MX                                                      UNPOP  17
      SIGN=1.                                                           UNPOP  18
      IF(M-NZ) 12,14,14                                                 UNPOP  19
   12 SIGN=-SIGN                                                        UNPOP  20
   14 CALL QECAL(O,NGAM,NGAM,NF,XSIG,ACAP,BCAP,THICK,RDBB,0.,UINF,XC(M),UNPOP  21
     1UE(M,1),SIGN)                                                     UNPOP  22
   15 CONTINUE                                                          UNPOP  23
      RETURN                                                            UNPOP  24
      END                                                               UNPOP  25
      SUBROUTINE ALSOL(NT, C, R)
      DOUBLE PRECISION C     NDIMC,NDIMC), R(130)                      ALSOL
      DOUBLE PRECISION CMAX,SAVE,SUM
      COMMON /BL1/       NTIME, NDIMC
      NT1 = NT-1
      DO 99 J=1,NT1
      CMAX = C(NT,J)
      L=NT
      DO 10 I=J,NT1
      IF (DABS(CMAX)-DABS(C(I,J))) 5,10,10
5     CMAX = C(I,J)
      L=I
10    CONTINUE
      DO 15 JJ=J,NT
      SAVE = C(L,JJ)
      C(L,JJ) = C(J,JJ)
15    C(J,JJ) = SAVE/CMAX
      SAVE = R(L)
      R(L) = R(J)
      R(J) = SAVE/CMAX
      JP1 = J+1
      DO 25 I=JP1,NT
      DO 20 JJ=JP1,NT
20    C(I,JJ) = C(I,JJ) - C(I,J)*C(J,JJ)
25    R(I) = R(I) - R(J)*C(I,J)
99    CONTINUE
      R(NT) = R(NT)/C(NT,NT)
      DO 150 K=1,NT1
      I=NT-K
      IP1 = I+1
      SUM = 0.
      DO 125 J=IP1,NT
125   SUM = SUM + R(J)*C(I,J)
150   R(I) = R(I) - SUM
      RETURN
      END
      SUBROUTINE CPC(ISEP,NGAM,NF,XSIG,NSIG,XSIGA,NSIGA,XSIGB,NSIGB,ACAPCPC
     1,BCAP,THICK,RDBB,GAMAW,UINF,UDOT,SIGN,XC,DXI,CP)                  CPC
      DIMENSION XSIG(100),XSIGA(100),XSIGB(100),ACAP(30,3),BCAP(100,3)  CPC
      DIMENSION GAMAW(1000),THICK(24)                                   CPC
      THETA=ARCT(XC)                                                    CPC
      RECIP=1./(UINF*UINF)                                              CPC
      SUM=0.                                                            CPC
      ANGLE=0.                                                          CPC
      DO 5 N=1,NF                                                       CPC
      ANGLE=ANGLE+THETA                                                 CPC
5     SUM=SUM+THICK(N)*COS(ANGLE)                                       CPC
      CP=UDOT*RECIP*(THICK(1)+2.*(1.-XC)*SUM)                           CPC
      CALL QECAL(ISEP,NGAM,NSIG,NF,XSIG,ACAP,BCAP,THICK,RDBB,GAMAW(1),UICPC
     1NF,XC,U,SIGN)                                                     CPC
      CP=CP+2.*(SIGN*U/UINF-1.)                                         CPC
      CALL EGAMI(1,NGAM,ACAP,BCAP(1,1),XSIG(1),XSIG(NSIG+1),GAMAW(1),XC,CPC
     1VAL1)                                                             CPC
      CALL EGAMI(2,NGAM,ACAP,BCAP(1,2),XSIGA(1),XSIGA(NSIGA+1),GAMAW(2),CPC
     1XC,VAL2)                                                          CPC
      CALL EGAMI(3,NGAM,ACAP,BCAP(1,3),XSIGB(1),XSIGB(NSIGB+1),GAMAW(3),CPC
     1XC,VAL3)                                                          CPC
      CP=CP+SIGN*RECIP*(1.5*VAL1-2.*VAL2+.5*VAL3)/DXI                   CPC
      IF(ISEP) 20,20,10                                                 CPC
10    CALL ESIGI(1,NSIG,XSIG,BCAP,XC,VAL1)                              CPC
      CALL ESIGI(2,NSIGA,XSIGA,BCAP,XC,VAL2)                            CPC
      CALL ESIGI(3,NSIGB,XSIGB,BCAP,XC,VAL3)                            CPC
      CP=CP+RECIP*(1.5*VAL1-2.*VAL2+.5*VAL3)/DXI                        CPC
20    CP=-CP                                                            CPC
      RETURN                                                            CPC
      END
      SUBROUTINE CLCM(NCOI,ISEP,NGAM,XSIG,NSIG,XSIGA,NSIGA,XSIGB,NSIGB,ACLCM    1
     1CAP,BCAP,THICK,RDBB,GAMAW,UINF,UDOT,DXI,AROT,CMPA)                CLCM    2
      COMMON /CLCMBL/   CLVB, CMVB,  CMPAVB                             MAIN
      DIMENSION ARGL(21),ARGM(21)                                       CLCM    3
      DIMENSION GAMAW(1000),THICK(24)                                   CLCM    4
      DIMENSION XSIG(100),XSIGA(100),XSIGB(100),ACAP(30,3),BCAP(100,3)  CLCM    5
    4 FORMAT(//40X,4HCL =E13.5/40X,4HCM =E13.5,17H (ABOUT MIDCHOR))/40X,CLCM    6
     14HCM =E13.5,24H (ABOUT PITCH AXIS - A =F7.4,1H))                  CLCM    7
      MOUT=6                                                            CLCM    8
      SAVE=THICK(1)                                                     CLCM    9
      THICK(1)=0.                                                       CLCM   10
      DT=3.14159/FLOAT(NCOI)                                            CLCM   11
      CL=0.                                                             CLCM   12
      CM=0.                                                             CLCM   13
      XI=-1.                                                            CLCM   14
      ANGLE=0.                                                          CLCM   15
      FLI=0.                                                            CLCM   16
      FMI=0.                                                            CLCM   17
      IF(ISEP) 5,5,7                                                    CLCM   18
    7 XATT=XSIG(NSIG+1)                                                 CLCM   19
      IF(XATT-.95) 8,5,5                                                CLCM   20
    8 XAQ=XATT+5.E-4                                                    CLCM   21
      XAP=XAQ+.025                                                      CLCM   22
      C1=-.5*(1.+XATT)                                                  CLCM   23
      C2=C1+XATT                                                        CLCM   24
      C1P=.5*(1.-XAP)                                                   CLCM   25
      C2P=C1P+XAP                                                       CLCM   26
      DO 10 I=1,NCOI                                                    CLCM   27
      ANGLE=ANGLE+DT                                                    CLCM   28
      XIP1=C1*COS(ANGLE)+C2                                             CLCM   29
      CALL CPC(ISEP,NGAM,1,XSIG,NSIG,XSIGA,NSIGA,XSIGB,NSIGB,ACAP,BCAP,TCLCM   30
     1HICK,RDBB,GAMAW,UINF,UDOT,1.0,XIP1,DXI,CPU)                       CLCM   31
      CALL CPC(ISEP,NGAM,1,XSIG,NSIG,XSIGA,NSIGA,XSIGB,NSIGB,ACAP,BCAP,TCLCM   32
     1HICK,RDBB,GAMAW,UINF,UDOT,-1.,XIP1,DXI,CPL)                       CLCM   33
      FLIP1=CPL-CPU                                                     CLCM   34
      FMIP1=XIP1*FLIP1                                                  CLCM   35
      CL=CL+(XIP1-XI)*(FLIP1+FLI)                                       CLCM   36
      CM=CM+(XIP1-XI)*(FMIP1+FMI)                                       CLCM   37
      XI=XIP1                                                           CLCM   38
      FLI=FLIP1                                                         CLCM   39
   10 FMI=FMIP1                                                         CLCM   40
      XI=1.                                                             CLCM   41
      FLI=0.                                                            CLCM   42
      FMI=0.                                                            CLCM   43
      ANGLE=0.                                                          CLCM   44
      DO 15 I=1,NCOI                                                    CLCM   45
      ANGLE=ANGLE+DT                                                    CLCM   46
      XIP1=C1P*COS(ANGLE)+C2P                                           CLCM   47
      CALL CPC(ISEP,NGAM,1,XSIG,NSIG,XSIGA,NSIGA,XSIGB,NSIGB,ACAP,BCAP,TCLCM   48
     1HICK,RDBB,GAMAW,UINF,UDOT,1.0,XIP1,DXI,CPU)                       CLCM   49
      CALL CPC(ISEP,NGAM,1,XSIG,NSIG,XSIGA,NSIGA,XSIGB,NSIGB,ACAP,BCAP,TCLCM   50
     1HICK,RDBB,GAMAW,UINF,UDOT,-1.,XIP1,DXI,CPL)                       CLCM   51
      FLIP1=CPL-CPU                                                     CLCM   52
      FMIP1=XIP1*FLIP1                                                  CLCM   53
      CL=CL-(XIP1-XI)*(FLIP1+FLI)                                       CLCM   54
      CM=CM-(XIP1-XI)*(FMIP1+FMI)                                       CLCM  55
      XI=XIP1                                                           CLCM  56
      FLI=FLIP1                                                         CLCM  57
   15 FMI=FMIP1                                                         CLCM  58
      XIP1=XAQ                                                          CLCM  59
      DO 16 I=1,21                                                      CLCM  60
      CALL CPC(ISEP,NGAM,1,XSIG,NSIG,XSIGA,NSIGA,XSIGB,NSIGB,ACAP,BCAP,TCLCM  61
     1HICK,RDBB,GAMAW,UINF,UDOT,1.0,XIP1,DXI,CPU)                       CLCM  62
      CALL CPC(ISEP,NGAM,1,XSIG,NSIG,XSIGA,NSIGA,XSIGB,NSIGB,ACAP,BCAP,TCLCM  63
     1HICK,RDBB,GAMAW,UINF,UDOT,-1.,XIP1,DXI,CPL)                       CLCM  64
      ARGL(I)=CPL-CPU                                                   CLCM  65
      ARGM(I)=XIP1*ARGL(I)                                              CLCM  66
   16 XIP1=XIP1+.00125                                                  CLCM  67
      SUML=0.                                                           CLCM  68
      SUMM=0.                                                           CLCM  69
      DO 17 I=1,19,2                                                    CLCM  70
      SUML=SUML+2.*ARGL(I)+4.*ARGL(I+1)                                 CLCM  71
   17 SUMM=SUMM+2.*ARGM(I)+4.*ARGM(I+1)                                 CLCM  72
      CL=CL+0.833333E-3*(SUML+ARGL(21)-ARGL(1))                         CLCM  73
      CM=CM+0.833333E-3*(SUMM+ARGM(21)-ARGM(1))                         CLCM  74
      BCON=16.*BCAP(1,1)*SQRT(5.E-4*(XATT-XSIG(1)))/UINF                CLCM  75
      CL=CL+BCON                                                        CLCM  76
      CM=CM+XATT*BCON                                                   CLCM  77
      GO TO 100                                                         CLCM  78
    5 DO 99 I=1,NCOI                                                    CLCM  79
      ANGLE=ANGLE+DT                                                    CLCM  80
      XIP1=-COS(ANGLE)                                                  CLCM  81
      CALL CPC(ISEP,NGAM,1,XSIG,NSIG,XSIGA,NSIGA,XSIGB,NSIGB,ACAP,BCAP,TCLCM  82
     1HICK,RDBB,GAMAW,UINF,UDOT,1.0,XIP1,DXI,CPU)                       CLCM  83
      CALL CPC(ISEP,NGAM,1,XSIG,NSIG,XSIGA,NSIGA,XSIGB,NSIGB,ACAP,BCAP,TCLCM  84
     1HICK,RDBB,GAMAW,UINF,UDOT,-1.,XIP1,DXI,CPL)                       CLCM  85
      FLIP1=CPL-CPU                                                     CLCM  86
      FMIP1=XIP1*FLIP1                                                  CLCM  87
      CL=CL+(XIP1-XI)*(FLIP1+FLI)                                       CLCM  88
      CM=CM+(XIP1-XI)*(FMIP1+FMI)                                       CLCM  89
      XI=XIP1                                                           CLCM  90
      FLI=FLIP1                                                         CLCM  91
   99 FMI=FMIP1                                                         CLCM  92
  100 CL=.25*CL                                                         CLCM  93
      CM=-.125*CM                                                       CLCM  94
      CMPA=CM+AROT*CL*.5                                                CLCM  95
      WRITE(MOUT,4) CL,CM,CMPA,AROT                                     CLCM  96
      THICK(1)=SAVE                                                     CLCM  97
      CLVB = CL                                                         MAIN
      CMVB = CM                                                         MAIN
      CMPAVB = CMPA                                                     MAIN
      RETURN                                                            CLCM  98
      END
      SUBROUTINE QECAL(ISEP,NGAM,NSIG,NF,XSIG,ACAP,BCAP,THICK,RDBB,GAMMA
     1,UINF,XC,U,SIGN)
      DIMENSION ACAP(30,3),BCAP(100,3),XSIG(100)
      DIMENSION THICK(24)
      EPS=1.E-6
      CORR=.707107/(1.-.63662*SQRT(RDBB)+.25*RDBB)
      SINT=SQRT(1.-XC*XC)
      THETA=ARCT(XC)
      COUNT=0.
      SUM=0.
      SINT2=SIN(.5*THETA)
      COST2=COS(.5*THETA)
      IF(SINT -EPS) 4,6,6
4     FACT=THETA*.5
      GO TO 8
6     FACT=(1.-XC)/SINT
8     DO 10 N=1,NF
      COUNT=COUNT+1.
      ANGLE=THETA*COUNT
      SUM=SUM+THICK(N)*(COUNT*FACT*SIN(ANGLE)-COS(ANGLE))
10    CONTINUE
      U=2.*SIGN*UINF*COST2*SUM+ACAP(1,1)*SINT2+.25*COST2*(1.+XC)*(3.*XC-
     11.)*GAMMA
      SUM=0.
      ANGLE=0.
      DO 12 N=1,NGAM
      ANGLE=ANGLE+THETA
12    SUM=SUM+ACAP(N+1,1)*SIN(ANGLE)
      U=U+COST2*SUM
      IF(ISEP) 25,99,25
25    SUM=0.
      XSEP=XSIG(1)
      XATT=XSIG(NSIG+1)
      DO 40 N=2,NSIG
40    SUM=SUM+BCAP(N,1)*FB(XSIG(N-1),XSIG(N),XSIG(N+1),XC)
      IF(XC-XATT-EPS) 45,45,46
46    FACT=(1.-XATT)**(-1.5)*SQRT((XATT-XSEP)*(1.-XC)/(XC-XATT))*(1.+3.*
     1XATT-4.*XC)-SIGN*(1.-SQRT((XSEP-XC)/(XATT-XC)))
      GO TO 55
45    IF(XSEP-XC) 49,49,48
48    FACT=-SIGN*(1.-SQRT((XSEP-XC)/(XATT-XC)))
      GO TO 55
49    FACT=-SIGN
55    U=U+COST2*(BCAP(1,1)*FACT+SIGN*SJM)
99    U=(SIGN*UINF*SQRT(1.+XC)+   CORR*U)/SQRT(1.+XC+.5*RDBB)
      RETURN
      END
      SUBROUTINE YVB(Y, I)                                                  YVB
      REAL Y(10)                                                            YVB
      REAL  MVB                                                             YVB
      COMMON /INPTVB/   FTVB(64),  FPVB(64),  FPPRVB(64),  DIDRVB(64),      YVB
     A      XMVB(64),   DELVB,     XMUVB,     FOVB,    XMUAVB,              YVB
     B      ATOVB,      ATCVB,     ATSVB,     ROVB,        RVB(64),         YVB
     C      MVB(64),    NVB                                                 YVB
      Y(1) =  (RVB(I) - DELVB)**2  *  MVB(I)                                YVB
      Y(2) =  FPVB(I)**2 *  MVB(I)                                          YVB
      Y(3) =  FTVB(I)**2  * DIDRVB(I)                                       YVB
      Y(4) = (DELVB - RVB(I)) * FTVB(I) * XMVB(I) * MVB(I)                  YVB
      Y(5) = FPVB(I) * FTVB(I) * XMVB(I) * MVB(I)                           YVB
      Y(6) =  RVB(I) * (DELVB - RVB(I))* MVB(I)                             YVB
      Y(8) =  (RVB(I) - DELVB) * FPPRVB(I) * FTVB(I) * XMVB(I) * MVB(I) YVB
      IP1 = I+1                                                             YVB
      IF(IP1 .GE. NVB) GO TO 12                                             YVB
      SUM = 0.                                                              YVB
      DO 10  J = IP1, NVB                                                   YVB
   10 SUM = SUM -(RVB(4+1) - RVB(4)) * (RVB(4+1) * MVB(J+1)                 YVB
     A       +  RVB(J) * MVB(J))                                            YVB
   12 Y(7) = FPPRVB(I) ** 2  * SUM / 2.                                     YVB
      RETURN                                                                YVB
      END
      SUBROUTINE POLLY(N,BBS,REL,AN,AA)
      IMPLICIT REAL*8 (A-H,O-Z)
C     COMPLEX ROOTS OF A POLYNOMIAL BAIRSTOWS METHOD
      DIMENSION A(30),AN(60),C(26),ABAR(26),B(30),AA(30)
      III=1
    7 NP1=N+1
      NPP1=N+2
      DO 601 I=1,NP1
      LLL=NPP1-I
  601 A(I)=AA(LLL)
   13 DO 14 K=1,NP1
   14 ABAR(K)=A(K)
      ABSSQ=BBS*BBS
      RELSQ=REL*REL
      NBAR=N
      B(1)=A(1)
      C(1)=A(1)
   15 IF(NBAR-2)200,210,17
   17 P1=.2
      Q1=.1
   18 ITER=0
   19 P1=P1*5.
      Q1=Q1*10.
   33 P=P1
      Q=Q1
      NBP1=NBAR+1
   34 L=1
      LAST=NBAR
      DIFST=9.99D36
C     BAIRSTOW ITERATION
   37 B(2)=ABAR(2)-P*B(1)
      DO 40 K=3,NBP1
   40 B(K)=ABAR(K)-P*B(K-1)-Q*B(K-2)
   45 C(2)=B(2)-P*C(1)
      DO 50 K=3,LAST
   50 C(K)=B(K)-P*C(K-1)-Q*C(K-2)
      C(LAST)=C(LAST)-B(LAST)
      D=C(LAST-1)*C(LAST-1)-C(LAST)*C(LAST-2)
      DSQR=D*D
      IF(DSQR-1.D-36)19,19,60
   60 DELP=(B(LAST)*C(LAST-1)-B(LAST+1)*C(LAST-2))/D
      DELQ=(B(LAST+1)*C(LAST-1)-B(LAST)*C(LAST))/D
C     TEST FOR CONVERGENCE
      RELP=DELP/P
      RELQ=DELQ/Q
      RELPS=RELP*RELP
      RELQS=RELQ*RELQ
      DELSQ=RELPS+RELQS
      P=P+DELP
      Q=Q+DELQ
      IF(RELPS-RELSQ)70,70,65
   65 IF(DELP*DELP-ABSSQ)70,70,80
   70 IF(RELQS-RELSQ)120,120,75
   75 IF(DELQ*DELQ-ABSSQ)120,120,80
   80 GO TO (90,100),L
   90 ITER=ITER+1                                                       POLLY 56
      IF(250-ITER)310,37,37                                             POLLY 57
  100 IF(DTEST-DELSQ)34,34,110                                          POLLY 58
  110 DTEST=DELSQ                                                       POLLY 59
      B(2)=A(2)-P*B(1)                                                  POLLY 60
      DO 115 K=3,NP1                                                    POLLY 61
  115 B(K)=A(K)-P*B(K-1)-Q*B(K-2)                                       POLLY 62
      GO TO 45                                                          POLLY 63
C     ITERATION HAS CONVERGED                                           POLLY 64
  120 GO TO (130,140),L                                                 POLLY 65
  130 L=2                                                               POLLY 66
      LAST=N                                                            POLLY 67
      GO TO 110                                                         POLLY 68
C     FACTOR OUT QUADRATIC                                              POLLY 69
  140 NBAR=NBAR-2                                                       POLLY 70
      NBP1=NBAR+1                                                       POLLY 71
      ABAR(2)=ABAR(2)-P*ABAR(1)                                         POLLY 72
      DO 150 K=3,NBP1                                                   POLLY 73
  150 ABAR(K)=ABAR(K)-P*ABAR(K-1)-Q*ABAR(K-2)                           POLLY 74
      GO TO  250                                                        POLLY 75
C     SOLVE LINEAR EQUATION                                             POLLY 76
  200 NBAR=NBAR-1                                                       POLLY 77
      R1=-ABAR(2)/ABAR(1)                                               POLLY 78
      R2=0.                                                             POLLY 79
      GO TO 262                                                         POLLY 80
C     NORMALIZE QUADRATIC                                               POLLY 81
  210 P=ABAR(2)/ABAR(1)                                                 POLLY 82
      Q=ABAR(3)/ABAR(1)                                                 POLLY 83
      NBAR=NBAR-2                                                       POLLY 84
C     SOLVE NORMALIZED QUADRATIC                                        POLLY 85
  250 R1=-P/2.                                                          POLLY 86
      C1=R1*R1-Q                                                        POLLY 87
      IF(C1)270,280,260                                                 POLLY 88
  260 C1=DSQRT(C1)                                                      POLLY 89
      R2=R1-C1                                                          POLLY 90
      R1=R1+C1                                                          POLLY 91
  262 C1=0.                                                             POLLY 92
      GO TO 290                                                         POLLY 93
  270 C1=-C1                                                            POLLY 94
      C1=DSQRT(C1)                                                      POLLY 95
  280 R2=R1                                                             POLLY 96
  290 C2=-C1                                                            POLLY 97
      AN(III)=C1                                                        POLLY 98
      AN(III+1)=R1                                                      POLLY 99
      AN(III+2)=C2                                                      POLLY100
      AN(III+3)=R2                                                      POLLY101
      III=III+4                                                         POLLY102
      IF(NBAR-1)4,200,15                                                POLLY103
C     SPECIAL CONDITIONS                                                POLLY104
  310 WRITE (6,600)                                                     POLLY105
  600 FORMAT(1X,50HNO CONVERGENCE IN 250 ITERATIONS ,POLLY HAS SPOKEN)  POLLY106
    4 CONTINUE                                                          POLLY107
      RETURN                                                            POLLY108
      END
      SUBROUTINE SETUP(LGO,M,NV,REB,X,Y,UC,PRESS,GRAD,DELT,DISP,THETA,VI
     1SC,MTRAN)
C
C  SUBROUTINE FOR CALCULATION OF BOUNDARY LAYER THICKNESS,
C  DISPLACEMENT THICKNESS, MOMENTUM THICKNESS AND EDDY VISCOSITY.
C
      DIMENSION X(300),Y(100),UC(100,3),VISC(100,2),GRAD(100)
      RTR=SQRT(REB)
      NY = NV + 2
      UEDGE = .995*UC(NY,1)
      DO 10 N=1,NV
      IF(UEDGE-UC(N+1,1)) 41,41,10
   41 NDELT = N
      GO TO 20
   10 CONTINUE
   20 DELT = Y(NDELT)+(UEDGE-UC(NDELT,1))*(Y(NDELT+1)-Y(NDELT))/(UC(NDEL
     1T+1,1)-UC(NDELT,1))
      SUM = 0.
      DO 50 N=2,NY
   50 SUM = SUM+(Y(N)-Y(N-1))*(UC(N,1)+UC(N-1,1))
      DISP = (Y(NY)-.5*SUM/UC(NY,1))/RTR
      SUM = 0.
      UEDGE = UC(NY,1)
      DO 60 N=2,NY
   60 SUM = SUM+(Y(N)-Y(N-1))*((UEDGE-UC(N,1))*UC(N,1)+(UEDGE-UC(N-1,1))
     1*UC(N-1,1))
      THETA = .5*SUM/(RTR*UEDGE**2)
      IF(LGO) 53,53,56
   53 NVP1=NV+1
      EASE = 1.
      IF(M-MTRAN) 31,32,32
   32 IF(MTRAN+5-M) 31,31,33
   33 EASE = (X(M)-X(MTRAN))/(X(MTRAN+5)-X(MTRAN))
   31 CONTINUE
      INNER=0
      FAC1 = .16*RTR*EASE
      FAC2 = .0168*UEDGE*DISP*REB*EASE
      EFAC1 = -RTR/26.
      EFAC2 = PRESS/RTR
      TAUW = GRAD(1)/RTR
      DO 160 N=2,NVP1
      ALTER = 1.+FAC2/(1.+5.5*(Y(N)/DELT)**6)
      IF(INNER) 402,401,402
  402 VISC(N,1)=ALTER
      GO TO 160
  401 CONTINUE
      TAUMY=TAUW-Y(N)*EFAC2
      IF(TAUMY) 701,701,702
  701 VISC(N,1)=1.
      GO TO 703
  702 EX=Y(N)*EFAC1*SQRT(TAUMY)
      VISC(N,1) = 1.+FAC1*Y(N)*Y(N)*ABS(GRAD(N))*(1.-EXP(EX))**2
  703 IF(VISC(N,1)-ALTER) 160,160,521
  521 VISC(N,1)=ALTER
      INNER=1
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16C   CONTINUE                                                    SETUP 56
      SAVE=1.                                                     SETUP 57
      DO 162 N=2,NV                                               SETUP 58
      RAVE=VISC(N,1)                                              SETUP 59
      VISC(N,1)=(VISC(N+1,1)+RAVE+SAVE)/3.                        SETUP 60
162   SAVF=RAVE                                                   SETUP 61
56    CONTINUE                                                    SETUP 62
      RETURN                                                      SETUP 63
      END
      SUBROUTINE MIXER(FPRES,PREC,UINF,UDOT,THICK,NF,XBSIG,NSIG,INDT,DEL
     11,THET1,REB,USEP,X4,CP4)
      DIMENSION FPRES(100),THICK(24),XBSIG(100)
      FCAP(X)=-19.556*X+107.535*X*X-336.33*X**3+508.1*X**4-295.96*X**5
      UI1(X)=-.46532*X+.68425*X*X-.45293*X**3+.6592*X**4
      UI2(X)=-.045929*X-1.91615*X*X+2.91843*X**3-5.42125*X**4
      DIST=.5*(XBSIG(2)-XBSIG(1))
      XSEP=XBSIG(1)-DIST
      XATT=XBSIG(NSIG)+DIST
C
C   IF INDT IS NONZERO, THE BOUNDARY LAYER IS TURBULENT
C   AT SEPARATION.
C
      CALL H4X4(INDT,XSEP,DEL1,THET1,XATT,REB,USEP,X3,H3,X4,H4)
      IF(XSEP-1.) 24,25,25
   25 CP4=0.
      GO TO 27
   24 URAT=EXP(-.08712-UI1(H4)-.24723*(.3255+UI2(H4)))
      CP4=1.-(1.-PREC)/URAT**2
      DEADL=XATT-XSEP
      IF(DEADL-2.) 5,6,6
    5 G=(.5*DEADL)**2
      GO TO 7
    6 G=1.
    7 CP4=PREC+(CP4-PREC)*(1.-G*XSEP)
   27 CONTINUE
      COEF=(PREC-CP4)/(XATT-X4)
      CZ=2.*UDOT/UINF
      C2 = -2.*UINF
      DO 20 M=1,NSIG
      SUM=0.
      COUNT=0.
      X=XBSIG(M)
      IF(X-1.) 2,2,3
    2 THETA = ARCT(X)
      TANT = SIN(.5*THETA)/COS(.5*THETA)
      CI = -CZ*(1.-COS(THETA))
      DO 10 N=1,NF
      COUNT=COUNT+1.
      ANGLE=COUNT*THETA
   10 SUM=SUM+THICK(N)*(CI*COS(ANGLE)+C2*(COUNT*TANT*SIN(ANGLE)-COS(ANGL
     1E)))
      SUM=SUM-.5*CZ*THICK(1)
      GO TO 35
    3 CI=CZ*(1.-X)
      XRAD=1./(X+SQRT(X*X-1.))
      CI=CZ*(X-1.)
      RF=SQRT((X-1.)/(X+1.))
      SUM=THICK(1)*XRAD*(C2*(RF-1.)-CZ*(1.-.5*XRAD))
      FRAD=XRAD
      COUNT=1.
      DO 30 N=2,NF
      COUNT=COUNT+1.
      FRAD=FRAD*XRAD
   30 SUM=SUM+THICK(N)*FRAD*(C2*(COUNT*RF-1.)+CI)
```

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35    CP=CP4                                                          MIXER 56
      IF(X-X4) 55,50,50                                               MIXER 57
50    CP=CP+(X-X4)*COEF                                               MIXER 58
55    CONTINUE                                                        MIXER 59
      FPRES(M)=-UINF*CP+SUM                                           MIXER 60
20    CONTINUE                                                        MIXER 61
      RETURN                                                          MIXER 62
      END                                                             MIXER 63
      SUBROUTINE BUBB(DEL1,THET1,REB,XC1,U1,XC5,DCP,DEL5,X,XC,MX,NZ,X5,U
     15,UE,ALTC,RENEL,USTOP)
      DIMENSION X(300),XC(300),UE(300,3)
      FCAP(X)=-19.556*X+107.535*X*X-336.33*X**3+508.1*X**4-295.96*X**5
      UI1(X)=-.46532*X+.68425*X*X-.45293*X**3+.6592*X**4
      UI2(X)=-.045929*X-1.91615*X*X+2.91843*X**3-5.42125*X**4
      FDELT(X)=EXP(2.5773-.34252*X-.4379*X*X-.076511*X**3-.0039707*X**4)
      FAICH(X)=EXP(-3.7481+.038772*X+.41967*X*X+.071046*X**3+.0032162*X*
     1*4)
      DELI(X)=-.045929*ALOG(X)-3.9242*X+.54535*X*X-1.39147*X**3-10.8425*
     1X**4
25    FORMAT(1H1,44X,31HANALYSIS OF LEADING-EDGE BUBBLE///34X,1HX,19X,1
     1HU,19X,1HH,18X,4HDISP/)
30    FORMAT(20X,4E20.5)
      MOUT=6
      H1=.25
      H5=.429
      DO 5 M=NZ,MX
      IF(XC1-XC(M)) 4,4,5
4     M1=M
      GO TO 6
5     CONTINUE
6     X1=X(M1-1)+(X(M1)-X(M1-1))*(XC1-XC(M1-1))/(XC(M1)-XC(M1-1))
      X4=X1+RENEL/(U1*REB)
      ARG=ALOG((X4-X1)/(REB*DEL1*DEL1*U1))
      H4=  .25*FAICH(ARG)
      DEL4=.58*FDELT(ARG)*DEL1
      X5=X4+10.5*DEL4*(1.-(H4/.429)**2)
      IF(U1-USTOP) 41,41,40
40    ALTL=ALTC*DEL1
      IF(X5-X1.LT.ALTL) X5=X1+ALTL
41    URAT=EXP(-.08712-UI1(H4)-.24723*(.3255+UI2(H4)))
      DCP=U1*U1*(1.-URAT**2)
      DRAT=EXP(-2.24374-FCAP(H4)+.24723*(2.0214+DELI(H4)))
      DEL5=DRAT*DEL4
      DO 7 M=NZ,MX
      IF(X5-X(M)) 16,16,7
16    M5=M
      GO TO 8
7     CONTINUE
8     FACT=(X5-X(M5-1))/(X(M5)-X(M5-1))
      FACT1=1.-FACT
      XC5=XC(M5-1)*FACT1+XC(M5)*FACT
      U5=UE(M5-1,1)*FACT1+UE(M5,1)*FACT
      WRITE(MOUT,25)
      WRITE(MOUT,30) X1,U1,H1,DEL1
      WRITE(MOUT,30) X4,U1,H4,DEL4
      WRITE(MOUT,30) X5,U5,H5,DEL5
      RETURN
      END
      SUBROUTINE YSET(R,A,NY,Y)
      DIMENSION Y(100)
      RP1=1.+R
      Y(1)=0.
      Y(2)=A
      DO 10 N=3,NY
   10 Y(N)=RP1*Y(N-1)-R*Y(N-2)
      RETURN
      END
      SURROUTINE H4X4(INOT,X1,DEL1,THET1,X5,REB,U1,X3,H3,X4,H4)
      CURLF(H)=26.703/H+305.03*ALOG(H)-2111.3*H+3327.8*H*H-2403.9*H**3
      FDELT(X)=EXP(2.5773-.34252*X-.4379*X*X-.076511*X**3-.0039707*X**4)
      FAICH(X)=EXP(-3.7481+.038772*X+.41967*X*X+.071046*X**3+.0032162*X*
     1*4)
   10 FORMAT(//20X,54HA SOLUTION FOR X4 COULD NOT BE OBTAINED IN 1000 TR
     1IALS)
      MOUT=6
C
C   IF INDT IS NONZERO, THE BOUNDARY LAYER IS TURBULENT
C   AT SEPARATION.
C
      IF(INDT) 2,5,2
 2    H3=THET1/DEL1
      X3=X1
      DEL3=DEL1
      GO TO 20
 5    X3=X1+5.E4/(U1*REB)
      ARG=ALOG((X3-X1)/(REB*DEL1*DEL1))
      H3=THET1*FAICH(ARG)/DEL1
      DEL3=.58*FDELT(ARG)*DEL1
      IF(X3-X5) 20,15,15
 15   H4=.429
      X4=X5
      GO TO 50
 20   CONTINUE
      IGO=0
      DIST=X5-X1
      UNDER=0.
      H4=H3+H3
      COEF1=DEL3*H3
      COEF2=10.5*DEL3*H3
      SUB=X3-COEF1*CURLF(H3)
 95   OVER=H4
      H4=.5*(H4+UNDER)
      X4=CURLF(H4)*COEF1+SUB
      ALTER=X5-COEF2*(1.-(H4/.429)**2)/H4
      IGO=IGO+1
      IF(X4-ALTER) 41,50,42
 41   IF(IGO-1000) 95,61,61
 42   IF(ABS(X4-ALTER)/DIST-.001) 50,50,43
 43   UNDER=H4
      H4=.5*(OVER+H4)
      X4=CURLF(H4)*COEF1+SUB
      ALTER=X5-COEF2*(1.-(H4/.429)**2)/H4
      IGO=IGO+1
      IF(X4-ALTER) 52,50,51
 51   IF(IGO-1000) 43,61,61
 52   IF(ABS(X4-ALTER)/DIST-.001) 50,50,95
 61   H4=.429
      X4=X5
      WRITE(MOUT,10)
 50   CONTINUE
      RETURN
      END
      SUBROUTINE SETSX(NSP1,XSEP,XATT,XSIG,ANGLE)
      DIMENSION XSIG(100)
      A=.5*(XSEP+XATT)
      B=.5*(XATT-XSEP)
      ARG=0.
      DO 5 N=1,NSP1
      XSIG(N)=A-B*COS(ARG)
 5    ARG=ARG+ANGLE
      RETURN
      END
      FUNCTION ARCT(X)                                              ARCT   1
      PI=3.14159                                                    ARCT   2
      IF(ABS(X)-1.E-6) 1,2,2                                        ARCT   3
 1    ARCT=.5*PI                                                    ARCT   4
      GO TO 6                                                       ARCT   5
 2    IF(X+.99999) 3,4,4                                            ARCT   6
 3    ARCT=PI                                                       ARCT   7
      GO TO 6                                                       ARCT   8
 4    ARCT=ATAN(SQRT(1.-X*X)/X)                                     ARCT   9
      IF(ARCT) 5,6,6                                                ARCT  10
 5    ARCT=ARCT+PI                                                  ARCT  11
 6    CONTINUE                                                      ARCT  12
      RETURN                                                        ARCT  13
      END                                                           ARCT  14
      FUNCTION GAM1(ACAP,DXI,PI)
      DIMENSION ACAP(30,3)
      GAM1=PI*(-1.5*ACAP(1,1)-.75*ACAP(2,1)+2.*ACAP(1,2)+ACAP(2,2)-.5*AC
     1AP(1,3)-.25*ACAP(2,3))/DXI
      RETURN
      END
      FUNCTION FB(X1,X2,X3,Y)
      D1=1./(X2-X1)
      D2=1./(X3-X2)
      T1=ABS(Y-X1)
      T2=ABS(Y-X2)
      T3=ABS(Y-X3)
      EPS=1.E-6
      IF(T1-EPS) 2,3,3
2     F1=0.
      F2=ALOG(T2)
      F3=ALOG(T3)
      GO TO 10
3     F1=ALOG(T1)
      IF(T2-EPS) 4,5,5
4     F2=0.
      F3=ALOG(T3)
      GO TO 10
5     F2=ALOG(T2)
      IF(T3-EPS) 6,7,7
6     F3=0.
      GO TO 10
7     F3=ALOG(T3)
10    FB=((Y-X1)*F1*D1+(D1+D2)*(X2-Y)*F2+(Y-X3)*F3*D2)/3.14159
      RETURN
      END
      SUBROUTINE EGAMI(NU,NG,A,B,XSEP,XATT,GAMMA,Y,GI)
      DIMENSION A(30,3)
      SINT=SQRT(1.-Y*Y)
      THETA=ARCT(Y)
      SUM=0.
      COUNT=1.
      DO 6 N=2,NG
      COUNT=COUNT+1.
6     SUM=SUM+A(N+1,NU)*(SIN((COUNT+1.)*THETA)/(COUNT+1.)-SIN((COUNT-1.)
     1*THETA)/(COUNT-1.))
      GI=(3.14159-THETA+SINT)*(A(1,NU)+.5*A(2,NU))+.5*SUM-.25*GAMMA*(1.+
     1Y)*SINT*SINT
      IF(Y-XATT) 8,8,7
7     DIFF=1.-XATT
      IF(DIFF-1.E-6) 8,8,9
9     GI=GI+2.*B*DIFF**(-1.5)*SQRT((XATT-XSEP)*(1.-Y)*(Y-XATT))
8     CONTINUE
      RETURN
      END
      SUBROUTINE ESIGI(NU,NX,XS,B,Y,SI)
      DIMENSION XS(100),B(100,3)
      SUM=0.
      DO 10 I=2,NX
10    SUM=SUM+B(I,NU)*GB(XS(I-1),XS(I),XS(I+1),Y)
      SI=B(1,NU)*BINT(XS(1),XS(NX+1),Y)+SUM
      RETURN
      END
      FUNCTION GB(X1,X2,X3,X)                                         GB    1
      GB=ABINT(X1,X2,X)-ABINT(X3,X2,X)                                GB    2
      GB=GB/3.14159                                                   GB    3
      RETURN                                                          GB    4
      END                                                             GB    5
      FUNCTION ABINT(A,B,X)
      ARGA=ABS(X-A)
      ARGB=ABS(X-B)
      COEF=2.*(B-A)
      AP1=A+1.
      BP1=B+1.
      IF(ARGA-1.E-6) 2,3,3
2     CA=0.
      GO TO 5
3     CA=ALOG(ARGA)
      IF(ARGB-1.E-6) 4,5,5
4     CB=0.
      GO TO 6
5     CB=ALOG(ARGB)
6     ABINT=(CA-.5)*ARGA**2-(CB-.5)*ARGB**2-(ALOG(AP1)-.5)*AP1**2+(ALOG(
     1BP1)-.5)*BP1**2-COEF*((X-B)*(CB-1.)+BP1*(ALOG(BP1)-1.))
      ABINT=ABINT/COEF
      RETURN
      END
      FUNCTION BINT(XS,XZ,X)
      RTS=SQRT(1.+XS)
      RTZ=SQRT(1.+XZ)
      BINT=-1.-X+RTS*RTZ
      IF(XZ-X) 2,3,3
2     RTSX=SQRT(X-XS)
      RTZX=SQRT(X-XZ)
      BINT=BINT+(XZ-XS)*ALOG((RTSX+RTZX)/(RTS+RTZ))+RTSX*RTZX
      GO TO 50
3     IF(X-XS) 5,5,4
4     BINT=BINT+(XZ-XS)*ALOG(SQRT(XZ-XS)/(RTS+RTZ))
      GO TO 50
5     RTSX=SQRT(XS-X)
      RTZX=SQRT(XZ-X)
      BINT=BINT+(XZ-XS)*ALOG((RTSX+RTZX)/(RTS+RTZ))-RTSX*RTZX
50    CONTINUE
      RETURN
      END
      SUBROUTINE SCAL(SBL,NSBL,FRZ,ARR,RDBB)
      DIMENSION SBL(300)
      DELZ=FRZ*RDBB
      EN=ARR/FRZ
      DO 5 N=1,300
      IF(EN-N) 4,4,5
    4 NE=N
      GO TO 6
    5 CONTINUE
    6 NG=NSBL-NE
      EN=FLOAT(NG)
      NGM1=NG-1
      SBL(1)=0.
      DO 7 N=2,NE
    7 SBL(N)=SBL(N-1)+DELZ
      FRACT=2.2/DELZ
      FRAC1=FRACT-1.
      R=FRACT**(1./FLOAT(NGM1))
    8 SAVE=R
      R=R-(R**NG-FRACT*R+FRAC1)/(EN*R**NGM1-FRACT)
      IF(ABS(SAVE-R)-1.E-6) 9,9,8
    9 RP1=R+1.
      DO 10 N=NE,NSBL
   10 SBL(N+1)=RP1*SBL(N)-R*SBL(N-1)
      RETURN
      END
      SUBROUTINE TERPF(XI,J,TAB1,TAB2,TAB3,TAB4,XITAB,FP)
      DIMENSION TAB1(24),TAB2(24),TAB3(24),TAB4(24),XITAB(24)
      IF(XI-.0001) 2,2,10
2     GO TO (3,4,5,6),J
3     FP=2.53-2.439*ALOG(XI)
      GO TO 99
4     FP=3.54-1.725*ALOG(.7071*XI)
      GO TO 99
5     FP=4.58-1.2195*ALOG(.5*XI)
      GO TO 99
6     FP=10.12
      GO TO 99
10    DO 12 N=1,24
      IF(XI-XITAB(N)) 11,11,12
11    NX=N
      GO TO 13
12    CONTINUE
13    TX=(XI-XITAB(NX-1))/(XITAB(NX)-XITAB(NX-1))
      TX1=1.-TX
      GO TO (14,15,16,17),J
14    FP=TX1*TAB1(NX-1)+TX*TAB1(NX)
      GO TO 99
15    FP=TX1*TAB2(NX-1)+TX*TAB2(NX)
      GO TO 99
16    FP=TX1*TAB3(NX-1)+TX*TAB3(NX)
      GO TO 99
17    FP=TX1*TAB4(NX-1)+TX*TAB4(NX)
99    CONTINUE
      RETURN
      END
      SUBROUTINE EVAL(NNF,XX,SSC,SST,CCB,TTB,CCM,TTM)
      DIMENSION SSC(50),SST(50)
      COST = 2.*XX - 1.
      COSTS = COST**2
      IF(COSTS-1.E-8) 303,304,304
  304 TANT = SQRT(1./COSTS - 1.)
      THE = ATAN(TANT)
      GO TO 305
  303 THE = 1.5708
  305 IF(COST) 403,404,404
  403 THE = 3.14159 - THE
  404 ARG = 0.
      SUM1 = 0.
      SUM2 = 0.
      DO 551 N=1,NNF
      ARG = ARG + THE
      SUM1 = SUM1 + SSC(N)*SIN(ARG)
  551 SUM2 = SUM2 + SST(N)*SIN(ARG)
      CCB = SUM1*SIN(THE)*CCM
      TTB = (1. - COS(THE))*SUM2*TTM
      RETURN
      END
      SUBROUTINE SIMP(NS,DX,ORD,FIND)                                   SIMP   1
      DIMENSION ORD(50)                                                 SIMP   2
C         INTEGRATION OF NS + 1 EQUALLY SPACED ORDINATE VALUES          SIMP   3
C         BY SIMPSON'S RULE.  NS MUST BE EVEN                           SIMP   4
      SUM = 0.                                                          SIMP   5
      DO 88 I=2,NS,2                                                    SIMP   6
   88 SUM = SUM + 2.*ORD(I-1) + 4.*ORD(I)                               SIMP   7
      FIND = DX*(SUM - ORD(1) + ORD(NS+1))/3.                           SIMP   8
      RETURN                                                            SIMP   9
      END                                                               SIMP  10
      SUBROUTINE SECT(XU,YU,XL,YL,NOFF,NF,RCDBC,TMAX,CMAX,ST,SC)
C   PROGRAM TO COMPUTE COEFFICIENTS TN AND CN OF THE FOURIER SERIES
C   REPRESENTATION OF SECTION THICKNESS AND CAMBER DISTRIBUTIONS
      DIMENSION XU(30),YU(30),XL(30),YL(30),YUC(30),YLC(30),ST(24),SC(24
     1),DUM(50),TBAR(50),CBAR(50)
   12 FORMAT(////47X,26HINPUT AND COMPUTED OFFSETS/)
   13 FORMAT(19X,4HX1/C,12X,4HYU/C,11X,5HYUC/C,20X,4HX1/C,12X,4HYL/C,11X
     1,5HYLC/C/)
   14 FORMAT(8X,3F16.5,8X,3F16.5)
      NA=6
      RNA=6.
      RNF=FLOAT(NF)
      MOUT=6
      PI = 3.14159
      DELT = PI/(2.*RNF)
      NTC = 2*NF - 1
      NINT = NTC + 2
      NSIMP = NTC + 1
      RDBC=.5*RCDBC
      VARY = 0.
      CB = 0.
      TB = 0.
      THETA = 0.
      DO 89 K=1,NTC
      THETA = THETA + DELT
      X1 = .5*(1. + COS(THETA))
      DO 90 LAM=2,NOFF
      IF(X1-XU(LAM)) 110,90,90
  110 YUINT = YU(LAM-1) + (X1 - XU(LAM-1))*(YU(LAM) - YU(LAM-1))/(XU(LAM
     1) - XU(LAM-1))
      GO TO 111
   90 CONTINUE
  111 DO 80 LAM=2,NOFF
      IF(X1-XL(LAM)) 210,80,80
  210 YLINT = YL(LAM-1) + (X1 - XL(LAM-1))*(YL(LAM) - YL(LAM-1))/(XL(LAM
     1) - XL(LAM-1))
      GO TO 112
   80 CONTINUE
  112 TBAR(K+1) = .5*(YUINT - YLINT)
   89 CBAR(K+1) = .5*(YUINT + YLINT)
      TMAX = 0.
      CMAX = 0.
      DO 79 K = 2,NSIMP
      IF(TBAR(K)-TMAX) 801,802,802
  802 TMAX = TBAR(K)
  801 IF(CBAR(K)-CMAX) 79,702,702
  702 CMAX = CBAR(K)
   79 CONTINUE
      IF(CMAX-1.E-5) 1201,1202,1202
 1201 CMAX=1.
 1202 CONTINUE
      IF(TMAX-1.E-5) 1140,1141,1141
 1140 TMAX=1.
 1141 DO 69 K=2,NSIMP
      TBAR(K) = TBAR(K)/TMAX
```

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69  CBAR(K) = CBAR(K)/CMAX                                               SECT  56
    TBAR(1) = 0.                                                          SECT  57
    CBAR(1) = 0.                                                          SECT  58
    TBAR(NINT) = 0.                                                       SECT  59
    CBAR(NINT) = 0.                                                       SECT  60
    TTA = TBAR(NA)                                                        SECT  61
    TTB = TBAR(NA+1)                                                      SECT  62
    TTC = TBAR(NA+2)                                                      SECT  63
    TAA = DELT*(RNA-1.)                                                   SECT  64
    TBB = TAA + DELT                                                      SECT  65
    TCC = TBB + DELT                                                      SECT  66
    XA = .5*COS(TAA)                                                      SECT  67
    XB = .5*COS(TBB)                                                      SECT  68
    XC = .5*COS(TCC)                                                      SECT  69
    SLOPE = ((TTC-TTB)*(XB-XA)/(XC-XB) + (TTB-TTA)*(XC-XB)/(XB-XA))/(XSECT  70
   1C-XA)                                                                 SECT  71
    THETA = 0.                                                            SECT  72
    COSB = COS(TBB)                                                       SECT  73
    DO 456 I=2,NA                                                         SECT  74
    THETA = THETA + DELT                                                  SECT  75
    COST = COS(THETA)                                                     SECT  76
456 TBAR(I) = (SQRT(1.-COST)/(1.-COSB)**1.5)*(TTB*(1.+COST-2.*COSB)/(1SECT  77
   1.-COSB) + .5*SLOPE*(COST-COSB))                                       SECT  78
    NLE = 2*NF + 1 - NA                                                   SECT  79
    COSR1 = 1. + COS(PI-RNA*DELT)                                         SECT  80
    THETA = PI                                                            SECT  81
    SINAS=SIN(RNA*DELT)**2                                                SECT  82
    COSAS=COS(RNA*DELT)                                                   SECT  83
    ANG=0.                                                                SECT  84
    DO 457 I=2,NA                                                         SECT  85
    IND = 2*NF + 2 - I                                                    SECT  86
    THETA = THETA - DELT                                                  SECT  87
    COST1 = 1. + COS(THETA)                                               SECT  88
    ANG=ANG+DELT                                                          SECT  89
    COEF=(SINAS-SIN(ANG)**2)/(COSR1*(COS(ANG)+COSAS))                     SECT  90
457 TBAR(IND) = (SQRT(RDBC*COST1)*COEF/TMAX+TBAR(NLE)*(COST1/COSR1)**1SECT  91
   1.5)/(2.-COST1)                                                        SECT  92
    THETA = TAA                                                           SECT  93
    NAP1 = NA + 1                                                         SECT  94
    DO 458 I = NAP1,NLE                                                   SECT  95
    THETA = THETA + DELT                                                  SECT  96
458 TBAR(I) = TBAR(I)/(1.-COS(THETA))                                     SECT  97
    THETA = 0.                                                            SECT  98
    DO 459 I=2,NSIMP                                                      SECT  99
    THETA = THETA + DELT                                                  SECT 100
459 CBAR(I) = CBAR(I)/SIN(THETA)                                          SECT 101
    RKK = 0.                                                              SECT 102
    DO 59 K=1,NF                                                          SECT 103
    RKK = RKK + 1.                                                        SECT 104
    THETA = 0.                                                            SECT 105
    DO 777 I=1,NINT                                                       SECT 106
    DUM(I) = TBAR(I)*SIN(THETA*RKK)                                       SECT 107
777 THETA = THETA + DELT                                                  SECT 108
    CALL SIMP(NSIMP,DELT,DUM,VARY)                                        SECT 109
    ST(K) = 2.*VARY/PI                                                    SECT 110
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      THETA = 0.
      DO 888 I=1,NINT
      DUM(I) = CBAR(I)*SIN(THETA*RKK)
  888 THETA = THETA + DELT
      CALL SIMP(NSIMP,DELT,DUM,VARY)
   59 SC(K) = 2.*VARY/PI
      DO 969 I=1,NOFF
      X = XU(I)
      CALL EVAL(NF,X,SC,ST,CB,TB,CMAX,TMAX)
  969 YUC(I) = CB + TB
      DO 869 I=1,NOFF
      X = XL(I)
      CALL EVAL(NF,X,SC,ST,CB,TB,CMAX,TMAX)
  869 YLC(I) = CB - TB
      SUM1 = 0.
      COUNT = 0.
      DO 699 I=1,NF
      COUNT = COUNT + 1.
  699 SUM1 = SUM1 - ST(I)*COUNT*(-1.)**I
      RCDBC = 8.*(TMAX*SUM1)**2
      RCDBC=2.*RCDBC
      TMAX=2.*TMAX
      CMAX=2.*CMAX
      WRITE(MOUT,12)
      WRITE(MOUT,13)
      WRITE(MOUT,14) (XU(I),YU(I),YUC(I),XL(I),YL(I),YLC(I),I=1,NOFF)
      RETURN
      END
      SUBROUTINE CORDX(NSBL,NZ,RDBB,SBL,X,XC)
C
C  BOUNDARY LAYER COORDINATES AND CORRESPONDING CHORDAL
C  COORDINATES ARE COMPUTED HERE.
C
      DIMENSION SBL(300),X(300),XC(300)
  336 FORMAT(//10X,31HITERATION TO COMPUTE XC FOR M =I5,32H DID NOT CONV
     1ERGE IN 1000 STEPS.)
  337 FORMAT(1H1,25X,1HM,20X,1HS,25X,1HX,24X,2HXC//)
  338 FORMAT(22X,I5,3E25.5)
      MOUT=6
      MX = NSBL + NZ - 1
      RZERO = RDBB/2.
      XC(NZ) = -1.
      DO 255 M=1,NZ
      MM = NZ + 1 - M
  255 X(M) = SBL(NZ) - SBL(MM)
      DO 256 M=NZ,MX
      MM = M + 1 - NZ
  256 X(M) = SBL(NZ) + SBL(MM)
      DO 257 M=1,MX
      IF(NZ-M) 333,257,335
  333 K = M + 1 - NZ
      GO TO 334
  335 K = NZ - M + 1
  334 XC(M) = -1. + SBL(K)
      IF(SBL(K)-RZERO) 341,341,342
  341 XC(M) = -1. + SBL(K)**2/(4.*RZERO)
  342 CONTINUE
      DO 258 L=1,1000
      SAVE = XC(M)
      CALC1 = SQRT((1.+XC(M))/RZERO)
      CALC2 = SQRT(1.+(1.+XC(M))/RZERO)
      XC(M)=XC(M)+CALC1*(SBL(K) -  RZERO*(CALC1*CALC2+ALOG(CALC1+CALC2))
     1)/CALC2
      IF(ABS(SAVE-XC(M))-1.E-6) 257,257,258
  258 CONTINUE
      WRITE(MOUT,336) M
  257 CONTINUE
      WRITE(MOUT,337)
      DO 264 M=1,MX
      IF(NZ-M) 261,261,262
  262 K=NZ-M+1
      GO TO 263
  261 K=M+1-NZ
  263 WRITE(MOUT,338) M,SBL(K),X(M),XC(M)
  264 CONTINUE
      RETURN
      END
      SUBROUTINE PGRAD(M,X,UE,DXI,PRESS,SA,SB,SC,SR,SS)
C
C   SUBROUTINE FOR CALCULATION OF PRESSURE GRADIENT AND
C   DERIVATIVE COEFFICIENTS.
C
      DIMENSION X(300),UE(300,3)
      D1Z=X(M+1)-X(M)
      D2Z=X(M+2)-X(M)
      D21=X(M+2)-X(M+1)
      D1M1=X(M+1)-X(M-1)
      DZM1=X(M)-X(M-1)
      XIM=D1Z/(D2Z*D21)
      ETAM=1./D1Z-1./D21
      ZETAM=D21/(D1Z*D2Z)
      PRESS = (3.*UE(M+1,1)-4.*UE(M+1,2)+UE(M+1,3))/(2.*DXI)+UE(M+1,1)*(
     1XIM*UE(M+2,1)+ETAM*UE(M+1,1)-ZETAM*UE(M,1))
      SA=1./D1Z+1./D1M1
      SB=D1M1/(D1Z*DZM1)
      SC=D1Z/(D1M1*DZM1)
      SR=D1M1/DZM1
      SS=D1Z/DZM1
      RETURN
      END
      SUBROUTINE TRANS(UPRIM,PRESS,THETA,REB,UC,NY,FLAM,XFLAM,LAMQ)     TRANS  1
C                                                                       TRANS  2
C   SUBROUTINE TO TEST FOR TRANSITION IN A LAMINAR BOUNDARY LAYER.      TRANS  3
C                                                                       TRANS  4
      DIMENSION UC(100,3),FLAM(10),XFLAM(10)                            TRANS  5
      F(X) = .11746 - 1.0582E-3*X - 1.1023E-4*X*X                       TRANS  6
      TKAY = PRESS*REB*THETA**2/UC(NY,2)                                TRANS  7
      IF(TKAY-.077) 2,2,99                                              TRANS  8
 2    IF(ABS(TKAY)-.0001) 3,3,4                                         TRANS  9
 3    ARG = TKAY*72.48                                                  TRANS 10
      GO TO 5                                                           TRANS 11
 4    ARG = 0.                                                          TRANS 12
      DO 6 N=1,1000                                                     TRANS 13
      SAVE = ARG                                                        TRANS 14
      ARG = ARG - (ARG*F(ARG)**2-TKAY)/(F(ARG)*(.11746-ARG*3.1746E-3 - ATRANS 15
     1RG*ARG*5.5115E-4))                                                TRANS 16
      IF(ABS(1.-SAVE/ARG)-1.E-6) 7,7,6                                  TRANS 17
 6    CONTINUE                                                          TRANS 18
 7    IF(ARG+11.) 8,8,5                                                 TRANS 19
 8    EF = 1.75                                                         TRANS 20
      GO TO 10                                                          TRANS 21
 5    DO 15 N=1,10                                                      TRANS 22
      IF(ARG-XFLAM(N)) 24,24,15                                         TRANS 23
 24   NBAR = N                                                          TRANS 24
      GO TO 16                                                          TRANS 25
 15   CONTINUE                                                          TRANS 26
 16   EF = FLAM(NBAR-1)+(ARG-XFLAM(NBAR-1))*(FLAM(NBAR)-FLAM(NBAR-1))/(XTRANS 27
     1FLAM(NBAR)-XFLAM(NBAR-1))                                         TRANS 28
 10   B = .5*EF                                                         TRANS 29
      A = 3.36*(UPRIM/UC(NY,2))**2                                      TRANS 30
      RTH = F(ARG)*(SQRT(B*B+9860.*A)-B)/A                              TRANS 31
      IF(REB*THETA-RTH) 99,50,50                                        TRANS 32
 50   LAMQ = 0                                                          TRANS 33
 99   CONTINUE                                                          TRANS 34
      RETURN                                                            TRANS 35
      END                                                               TRANS 36
      SUBROUTINE CAPS(ITER,N,CAPG,CAPH,CAPJ,CAPK,SR,SS,SD,SE,SF,VISC,V,UCAPS   1
     1C)                                                                CAPS   2
      DIMENSION CAPG(100),CAPH(100),CAPJ(100),CAPK(100)                 CAPS   3
      DIMENSION VISC(100,2),V(100,2),UC(100,3),SD(100),SE(100),SF(100)  CAPS   4
      IF(ITER) 4,2,4                                                    CAPS   5
    2 CAPG(N)= SR*V(N,1) - SS*V(N,2)                                    CAPS   6
      CAPH(N)=SR*VISC(N,1)-SS*VISC(N,2)                                 CAPS   7
      CAPJ(N)=SR*(SD(N)*VISC(N+1,1)+SE(N)*VISC(N,1)-SF(N)*VISC(N-1,1))-SCAPS   8
     1S*(SD(N)*VISC(N+1,2)+SE(N)*VISC(N,2)-SF(N)*VISC(N-1,2))           CAPS   9
      CAPK(N)= SR*UC(N,2)-SS*UC(N,3)                                    CAPS  10
      GO TO 6                                                           CAPS  11
    4 CAPG(N)=.5*(CAPG(N)+V(N,1))                                       CAPS  12
      CAPH(N)=.5*(CAPH(N)+VISC(N,1))                                    CAPS  13
      CAPJ(N)=.5*(CAPJ(N)+SD(N)*VISC(N+1,1)+SE(N)*VISC(N,1)-SF(N)*VISC(NCAPS  14
     1-1,1))                                                            CAPS  15
      CAPK(N)=.5*(CAPK(N)+UC(N,1))                                      CAPS  16
    6 CONTINUE                                                          CAPS  17
      RETURN                                                            CAPS  18
      END                                                               CAPS  19
      SUBROUTINE TERP(YIN,YBASE,VARY,NY,VALUE)
C
C  SUBROUTINE FOR DETERMINING INTERPOLATED VALUE OF THE
C   FUNCTION VARY AT Y = YIN.
C
      DIMENSION YBASE(100),VARY(100)
      IF(YIN-YBASE(NY-1)) 2,3,3
  3   VALUE = VARY(NY)
      GO TO 10
  2   DO 15 N=1,NY
      IF(YIN-YBASE(N)) 24,24,15
   24 NBAR=N
      GO TO 16
  15  CONTINUE
  16  D21=YBASE(NBAR)-YBASE(NBAR-1)
      D31=YBASE(NBAR+1)-YBASE(NBAR-1)
      D32=D31-D21
      D3A=YBASE(NBAR+1)-YIN
      D2A=YBASE(NBAR)-YIN
      DA1=YIN-YBASE(NBAR-1)
      VALUE=D3A*D2A*VARY(NBAR-1)/(D21*D31)+D3A*DA1*VARY(NBAR)/(D21*D32)-
     1D2A*DA1*VARY(NBAR+1)/(D31*D32)
  10  CONTINUE
      RETURN
      END
      SUBROUTINE YDIFF(NY,ALPHA,BETA,GAMMA,DELTA,SD,SE,SF,C2,C3,C4,Y)
      DIMENSION ALPHA(100),BETA(100),GAMMA(100),DELTA(100)
      DIMENSION SD(100),SE(100),SF(100),Y(100)
      NV=NY-2
      NVP1=NV+1
      DO 40 N=2,NV
      ALPHA(N) = 2.*(2.*Y(N)-Y(N-1)-Y(N+1))/((Y(N+2)-Y(N-1))*(Y(N+2)-Y(N
     1+1))*(Y(N+2)-Y(N)))
      DELTA(N) = 2.*(Y(N+2)+Y(N+1)-2.*Y(N))/((Y(N+2)-Y(N-1))*(Y(N+1)-Y(N
     1-1))*(Y(N)-Y(N-1)))
      BETA(N) = (DELTA(N)*(Y(N)-Y(N-1))**3-ALPHA(N)*(Y(N+2)-Y(N))**3)/(Y
     1(N+1)-Y(N))**3
      GAMMA(N) = -ALPHA(N)-BETA(N)-DELTA(N)
   40 CONTINUE
      DO 39 N=2,NVP1
      SD(N) = (Y(N)-Y(N-1))/((Y(N+1)-Y(N-1))*(Y(N+1)-Y(N)))
      SE(N) = 1./(Y(N)-Y(N-1))-1./(Y(N+1)-Y(N))
      SF(N) = (Y(N+1)-Y(N))/((Y(N)-Y(N-1))*(Y(N+1)-Y(N-1)))
   39 CONTINUE
      C2 = Y(3)*Y(4)/(Y(2)*(Y(3)-Y(2))*(Y(4)-Y(2)))
      C3 = -Y(2)*Y(4)/(Y(3)*(Y(4)-Y(3))*(Y(3)-Y(2)))
      C4 = Y(2)*Y(3)/(Y(4)*(Y(4)-Y(3))*(Y(4)-Y(2)))
      RETURN
      END
      SUBROUTINE ELDER(BCAP,XSIG,NSIG,UINF,ELD,Y,YMAX)                  ELDER   1
      DIMENSION BCAP(100,3),XSIG(100)                                   ELDER   2
      BCAP(NSIG+1,1)=0.                                                 ELDER   3
      XS=XSIG(1)                                                        ELDER   4
      XZ=XSIG(NSIG+1)                                                   ELDER   5
      IF(XZ-1.) 16,16,1                                                 ELDER   6
    1 DEADL=XZ-XS                                                       ELDER   7
      YMAX=1.E-10                                                       ELDER   8
      SUM=.5*(XSIG(2)-XS)*BCAP(2,1)                                     ELDER   9
      DO 10 N=2,NSIG                                                    ELDER  10
      X=XSIG(N+1)                                                       ELDER  11
      SUM=SUM+.5*(X-XSIG(N))*(BCAP(N+1,1)+BCAP(N,1))                    ELDER  12
      IF(N-NSIG) 4,2,4                                                  ELDER  13
    2 ANGLE=1.5708                                                      ELDER  14
      GO TO 6                                                           ELDER  15
    4 ANGLE=ATAN(SQRT((X-XS)/(XZ-X)))                                   ELDER  16
    6 Y=SUM+BCAP(1,1)*(DEADL*ANGLE-SQRT((X-XS)*(XZ-X)))                 ELDER  17
      IF(Y-YMAX) 10,10,8                                                ELDER  18
    8 YMAX=Y                                                            ELDER  19
   10 CONTINUE                                                          ELDER  20
      ELD=Y/YMAX                                                        ELDER  21
      IF(ABS(ELD)-UINF) 20,20,12                                        ELDER  22
   12 IF(ELD) 14,16,16                                                  ELDER  23
   14 ELD=-UINF                                                         ELDER  24
      GO TO 20                                                          ELDER  25
   16 ELD=UINF                                                          ELDER  26
   20 CONTINUE                                                          ELDER  27
      RETURN                                                            ELDER  28
      END                                                               ELDER  29
      SUBROUTINE REATT(UC,V,X,Y,MX,NY,RY,DRY,UE,X5,DEL5,MST,REB)
      DIMENSION UC(100,3),V(100,2),Y(100)
      DIMENSION X(300),UE(300,3)
      DIMENSION TAB1(24),TAB2(24),TAB3(24),TAB4(24),XITAB(24)
      DATA TAB1 /24.98,23.29,21.04,19.33,17.61,15.29,13.46,11.54,10.36,9
     1.38,8.35,7.32,6.29,5.31,4.4,3.57,2.22,1.26,.66,.31,.14,.01,0.,0./
      DATA TAB2 /20.05,18.85,17.25,16.04,14.8,13.12,11.77,10.3,9.36,8.65
     1,7.95,7.2,6.43,5.66,4.9,4.18,2.89,1.86,1.11,.62,.32,.04,0.,0./
      DATA TAB3 /16.65,15.8,14.67,13.8,12.91,11.66,10.65,9.48,8.71,8.11,
     17.59,7.01,6.41,5.77,5.13,4.5,3.31,2.28,1.48,.9,.51,.09,.01,0./
      DATA TAB4 /10.12,10.05,9.93,9.78,9.58,9.17,8.72,8.08,7.6,7.2,6.85,
     16.53,6.18,5.79,5.36,4.91,3.98,3.05,2.21,1.5,.95,.22,.03,0./
      DATA XITAB /.0001,.0002,.0005,.001,.002,.005,.01,.02,.03,.04,.05,.
     106,.07,.08,.09,.1,.12,.14,.16,.18,.2,.25,.3,.35/
3     FORMAT(///40X,23HAT REATTACHMENT, BETA =E13.5)
      MOUT=6
      RTR=SQRT(REB)
      UC(1,2)=0.
      UC(1,3)=0.
      V(1,1)=0.
      V(1,2)=0.
      DO 5 M=1,MX
      IF(X5-X(M)) 4,4,5
4     MST=M+2
      GO TO 6
5     CONTINUE
6     XA=X(MST-2)
      XB=X(MST-1)
      UA=UE(MST-2,1)
      UB=UE(MST-1,1)
      ZA=ALOG(UA*DEL5*REB)
      PGRAD=2.*(UA-UB)/((UA+UB)*(XB-XA))
      BETM2=(.0974-SQRT(DEL5*PGRAD))/(.0249+.004565*ZA)
      IF(BETM2-1.) 8,7,7
7     BETM2=1.
      GO TO 10
8     IF(BETM2-.3) 9,9,10
9     BETM2=.3
10    BETA=1./(BETM2*BETM2)
      WRITE(MOUT,3) BETA
      AGAM=.0974*BETM2-.0249/BETA
      BGAM=.004565/BETA
      AH=1.-(5.3+3.9*BETM2)*(.0974-.0249*BETM2)
      BH=BETM2*(5.3+3.9*BETM2)*.004565
      GAMA=AGAM-BGAM*ZA
      DERIV=UA*REB*EXP(-ZA)*GAMA*GAMA*(1.+BETA*(1.+AH+BH*ZA))/(AH+BH+BH*
     1ZA)
      ZB=ZA+DERIV*(XB-XA)
      DELB=EXP(ZB)/(UB*REB)
      GAMB=AGAM-BGAM*ZB
      DELL=.35*DELB*RTR*BETM2/GAMB
11    IF(DELL-Y(NY-3)) 14,12,12
12    RY=RY+DRY
      CALL YSET(RY,Y(2),NY,Y)
      GO TO 11
```

```
 14    IF(BETA-4.) 102,101,101                                          REATT 56
 101   TERPB=1.-4./BETA                                                 REATT 57
       INDEX=3                                                          REATT 58
       GO TO 110                                                        REATT 59
 102   IF(BETA-2.) 104,103,103                                          REATT 60
 103   TERPB=.5*BETA-1.                                                 REATT 61
       INDEX=2                                                          REATT 62
       GO TO 110                                                        REATT 63
 104   TERPB=BETA-1.                                                    REATT 64
       INDEX=1                                                          REATT 65
 110   K=0                                                              REATT 66
       TERP1=1.-TERPB                                                   REATT 67
 50    K=K+1                                                            REATT 68
       GO TO (16,17,99),K                                               REATT 69
 16    G=GAMA                                                           REATT 70
       DELTA=DELS                                                       REATT 71
       UEDGE=UA                                                         REATT 72
       L=3                                                              REATT 73
       GO TO 18                                                         REATT 74
 17    G=GAMB                                                           REATT 75
       DELTA=DELB                                                       REATT 76
       UEDGE=UB                                                         REATT 77
       L=2                                                              REATT 78
 18    XICO=G/(DELTA*RTR*BETM2)                                         REATT 79
       UCOW=RTR*(UEDGE*G)**2                                            REATT 80
       EFCO=G/BETM2                                                     REATT 81
       NLAM=NY                                                          REATT 82
       DO 75 N=2,NY                                                     REATT 83
       XI=Y(N)*XICO                                                     REATT 84
       IF(XI-.35) 20,19,19                                              REATT 85
 19    UC(N,L)=UEDGE                                                    REATT 86
       GO TO 75                                                         REATT 87
 20    CALL TERPF(XI,INDEX,TAB1,TAB2,TAB3,TAB4,XITAB,FP1)               REATT 88
       INDP1=INDEX+1                                                    REATT 89
       CALL TERPF(XI,INDP1,TAB1,TAB2,TAB3,TAB4,XITAB,FP2)               REATT 90
       FP=TERP1*FP1+TERPB*FP2                                           REATT 91
       UC(N,L)=UEDGE*(1.-EFCO*FP)                                       REATT 92
       IF(N-NLAM) 21,75,75                                              REATT 93
 21    ALTER=UCOW*Y(N)                                                  REATT 94
       IF(ALTER-UC(N,L)) 33,33,32                                       REATT 95
 32    UC(N,L)=ALTER                                                    REATT 96
       GO TO 75                                                         REATT 97
 33    NLAM=N                                                           REATT 98
 75    CONTINUE                                                         REATT 99
       GO TO 50                                                         REATT100
 99    DO 60 K=2,3                                                      REATT101
       SAVE2=0.                                                         REATT102
       DO 60 N=3,NY                                                     REATT103
       SAVE1=UC(N-1,K)                                                  REATT104
       UC(N-1,K)=(SAVE2+SAVE1+UC(N,K))/3.                               REATT105
 60    SAVE2=SAVE1                                                      REATT106
       DUDX=0.                                                          REATT107
       COD=.5/(XB-XA)                                                   REATT108
       DO 65 N=2,NY                                                     REATT109
       DUDXP=COD*(UC(N,2)-UC(N,3))                                      REATT110
```

```
      V(N,1)=V(N-1,1)-(Y(N)-Y(N-1))*(DUDXP+DUDX)                        REATT111
      V(N,2)=V(N,1)                                                     REATT112
65    DUDX=DUDXP                                                        REATT113
      RETURN                                                            REATT114
      END                                                               REATT115
      SUBROUTINE ELPIT(ALPH1,ALPH2,EMI,TORF,THETZ,UINF,DXI,CMPA,CMPAS)
      SAVET=ALPH1
      STEP=TORF*DXI
      SINS=SIN(STEP)
      COSS=COS(STEP)
      CONST=2.*EMI*(UINF/TORF)**2
      ALPH1=THETZ+(ALPH1-THETZ)*COSS+ALPH2*SINS/TORF+CONST*(2.*CMPA-CMPA
     1S)*(1.-COSS)+CONST*(CMPAS-CMPA)*(SINS-STEP*COSS)/(TORF*DXI)
      ALPH2=ALPH2*COSS-TORF*SINS*(SAVET-THETZ)+CONST*(CMPA-CMPAS)*(1.-CO
     1SS)/DXI+CONST*CMPA*TORF*SINS
      RETURN
      END
      SUBROUTINE VWASH(BARG,H,S,NVOR,X1,UINF,VZIP,XGAM,NGP1,DXI)
      DIMENSION VZIP(30),XGAM(30)
      DO 10 N=1,NGP1
      DIFF=XGAM(N)-X1
      SUM=0.
      DO 5 K=1,NVOR
      SUM=SUM+DIFF/(DIFF*DIFF+H)
5     DIFF=DIFF-S
10    VZIP(N)=VZIP(N)+SUM*BARG
      RETURN
      END
      SUBROUTINE WASH(XGAM,NGAM,TIME,ALPH1,ALPH2,HEAVE,AROT,FREQF,PHIH,U
     1INF,CAMBR,NF,VZIP,MOTR,INDV)
      DIMENSION XGAM(30),VZIP(30),CAMBR(24)
      NGP1 = NGAM+1
      ANGLE = FREQF*TIME
      GO TO (108,120), INDV
  108 GO TO (110,120),MOTR
  110 CONST =-ALPH2*COS(ANGLE)*UINF+HEAVE*COS(ANGLE+PHIH)+ALPH1*UINF
      FACT =-ALPH2*FREQF*SIN(ANGLE)*UINF
      GO TO 130
  120 CONST=UINF*ALPH1+HEAVE
      FACT=-UINF*ALPH2
  130 DO 10 M=1,NGP1
      X=XGAM(M)
      THETA = ARCT(X)
      SUM=0.
      COUNT=0.
      DO 20 N=1,NF
      COUNT=COUNT+1.
   20 SUM=SUM+COUNT*CAMBR(N)*COS(COUNT*THETA)
      IF(M-1) 2,4,2
    2 IF(NGP1-M) 3,4,3
    4 SUM = SUM + SUM
      GO TO 50
    3 COUNT = 0.
      COTT = X/SIN(THETA)
      DO 30 N=1,NF
      COUNT = COUNT+THETA
   30 SUM=SUM+COTT*CAMBR(N)*SIN(COUNT)
   50 VZIP(M) = UINF*SUM+CONST+FACT*(AROT-X)
   10 CONTINUE
      RETURN
      END
```

APPENDIX B

DETERMINATION OF COUPLING PARAMETERS

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DETERMINATION OF COUPLING PARAMETERS

The characteristic equation for the rotor blade is

$$\sum_{k=0}^{3} B_{2k} \lambda^{2k} = 0$$

where

$$B_0 = f_0 - \frac{\bar{\omega}_{\phi}^{2} T_{\beta\theta}^{2}}{M_{\beta\beta} M_{\theta\theta}} - \frac{\bar{\omega}_{\beta}^{2} T_{\phi\theta}^{2}}{M_{\phi\phi} M_{\theta\theta}}$$

$$B_2 = f_2 + 2 \frac{\bar{\omega}_{\phi}^{2} M_{\beta\theta} T_{\beta\theta}}{M_{\beta\beta} M_{\theta\theta}} + 2 \frac{\bar{\omega}_{\beta}^{2} M_{\phi\theta} T_{\phi\theta}}{M_{\phi\phi} M_{\theta\theta}}$$

$$- \frac{T_{\beta\theta}^{2}}{M_{\beta\beta} M_{\theta\theta}} - \frac{T_{\phi\theta}^{2}}{M_{\phi\phi} M_{\theta\theta}}$$

$$B_4 = f_4 - \frac{\bar{\omega}_{\phi}^{2} M_{\beta\theta}}{M_{\beta\beta} M_{\theta\theta}} - \frac{\bar{\omega}_{\beta}^{2} M_{\phi\theta}^{2}}{M_{\phi\phi} M_{\theta\theta}}$$

$$+ 2 \frac{M_{\beta\theta} T_{\beta\theta}}{M_{\beta\beta} M_{\theta\theta}} + 2 \frac{M_{\phi\theta} T_{\phi\theta}}{M_{\phi\phi} M_{\theta\theta}}$$

$$B_6 = 1 - \frac{M_{\beta\theta}^{2}}{M_{\beta\beta} M_{\theta\theta}} - \frac{M_{\phi\theta}^{2}}{M_{\phi\phi} M_{\theta\theta}}$$

in which

$$f_0 = \bar{\omega}_\beta^{\,2} \; \bar{\omega}_\phi^{\,2} \; \bar{\omega}_\theta^{\,2}$$

$$f_2 = \bar{\omega}_\beta^{\,2} \; \bar{\omega}_\phi^{\,2} + \bar{\omega}_\beta^{\,2} \; \bar{\omega}_\theta^{\,2} + \bar{\omega}_\phi^{\,2} \; \bar{\omega}_\theta^{\,2}$$

$$f_4 = \bar{\omega}_\beta^{\,2} + \bar{\omega}_\phi^{\,2} + \bar{\omega}_\theta^{\,2}$$

The characteristic equation for the two-dimensional system is found to be

$$\sum_{k=0}^{3} D_{2k} \; \lambda^{2k} = 0$$

where

$$D_0 = f_0 - \bar{\omega}_\phi^{\,2} \, h_a \; a_1^{\,2} - \bar{\omega}_\beta^{\,2} \, h_b \, b_1^{\,2}$$

$$D_2 = f_2 - \bar{\omega}_\phi^{\,2} \, g_a \, \bar{x} \; a_1 - \bar{\omega}_\beta^{\,2} \, g_b \, \bar{x} \, b_1$$

$$- h_a \; a_1^{\,2} - h_b \; b^{\,2}$$

$$D_4 = f_4 - C_4 \, \bar{x}^2 - g_a \, \bar{x} \; a_1 - g_b \, \bar{x} \, b_1$$

$$D_6 = 1 - C_6 \, \bar{x}^2$$

in which

$$h_a = \frac{M_{\beta\beta}}{R^2 \, M_{\theta\theta}} \qquad h_b = \frac{M_{\phi\phi}}{M_{\theta\theta}}$$

$$g_a = 2\,h_a\,A_1 \qquad g_b = 2\,h_b\,A_2$$

$$C_4 = \bar{\omega}_\phi{}^2\,h_a\,A_1{}^2 + \bar{\omega}_\beta{}^2\,h_b\,A_2{}^2$$

$$C_6 = h_a\,A_1{}^2 + h_b\,A_2{}^2$$

$$a_1 = A_1\,(\bar{\omega}_\beta{}^2\,l_{s_1} + r_m\,\bar{\omega}_\phi{}^2\,l_{s_2}) - B\,\bar{\omega}_\phi{}^2\,l_{s_2}$$

$$b_1 = A_2\,(\bar{\omega}_\beta{}^2\,l_{s_1} + r_m\,\bar{\omega}_\phi{}^2\,l_{s_2}) + B\,\bar{\omega}_\phi{}^2\,l_{s_2}$$

Equating D_0/D_6 to B_0/B_6, D_2/D_6 to B_2/B_6 and D_4/D_6 to B_4/B_6 provides three relations in the three unknowns $\bar{x}$, l_{s1}, and l_{s2}. If a_1 and b_1 are eliminated, the following equation for $\bar{x}$ is obtained:

$$(r_1\,t_2 - r_2\,t_1)^2 + (r_1\,s_2 - r_2\,s_1)(t_2\,s_1 - t_1\,s_2) = 0$$

where

$$r_1 = -\left[h_a + \frac{h_b\,g_a{}^2}{g_b{}^2}\right] \qquad r_2 = \left[\frac{\bar{\omega}_\phi{}^2}{\bar{\omega}_\beta{}^2} - 1\right] h_a$$

$$s_2 = (\bar{\omega}_\beta{}^2 - \bar{\omega}_\phi{}^2)\,g_a\,\bar{x}\,, \quad s_1 = s_2 + \frac{2\,h_b\,g_a\,F}{g_b{}^2\,\bar{x}}$$

$$t_1 = (1 - C_6\,\bar{x}^2)\,B_2/B_6 - f_2 + \bar{\omega}_\beta{}^2\,F + \frac{h_b\,F^2}{g_b{}^2\,\bar{x}^2}$$

$$t_2 = (1 - C_6 \bar{x}^2)(B_2 - B_0/\bar{\omega}_\beta^{\,2})/B_6 - f_2 + \bar{\omega}_\beta^{\,2} F + f_0/\bar{\omega}_\beta^{\,2}$$

in which

$$F = f_4 - B_4/B_6 + (B_4 C_6/B_6 - C_4) \bar{x}^2$$

With some algebraic manipulation, a polynomial of fourth degree in $\bar{x}^2$ can be extracted from that equation. The value of $\bar{x}$ is taken to be the square root of the smallest positive root of that polynomial. The original equations are then used to solve for a_1 and b_1, from which l_{s1} and l_{s2} are readily obtained.

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